U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-253 478

TREATMENT OF DENIM TEXTILE MILL WASTEWATERS
NEUTRALIZATION AND COLOR REMOVAL

CANTON TEXTILE MILLS, INCORPORATED

PREPARED FOR
INDUSTRIAL ENVIRONMENTAL RESEARCH
LABORATORY

MAY 1976

163193

EPA-600/2-76-139
May 1976

PB 253 478
Environmental Protection Technology Series

TREATMENT OF DENIM TEXTILE MILL WASTEWATERS: NEUTRALIZATION AND COLOR REMOVAL

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

Industrial Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

113

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-76-139	2.	3. RECIPIENT'S ACCESSION NO. PB-253 478
4. TITLE AND SUBTITLE Treatment of Denim Textile Mill Wastewaters: Neutralization and Color Removal		5. REPORT DATE May 1976 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Charles R. Froneberger and Michael J. Pollock		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS R.S. Noonan, Inc. of South Carolina P.O. Box 1388 Greenville, South Carolina 29602		10. PROGRAM ELEMENT NO. 1BB036; ROAP 21AZT-006 11. CONTRACT/GRANT NO. Grant S800852*
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 4/72-7/75 14. SPONSORING AGENCY CODE EPA-ORD

15. SUPPLEMENTARY NOTES (*) Grantee is Canton Textile Mills, Inc. Project officer for this report is T.N. Sargent, EPA, Cincinnati, Ohio 45268.

16. ABSTRACT The report describes a bench scale investigation using fly ash adsorption and chemical destabilization techniques to remove color from indigo and sulfur dyeing wastewaters from a denim textile mill. The investigation included a feasibility study and subsequent full scale demonstration flue gas wet scrubbing techniques for neutralizing caustic wastewaters. The fly ash adsorption studies demonstrated that fly ash from a coal-fired boiler can adsorb and subsequently remove color, BOD5, and COD from biologically treated domestic and dyeing process wastewaters. The limited adsorbtion capacity of the fly ash and problems related to fly ash/wastewater contact made full scale application impractical. The chemical destabilization studies included investigation of 11 destabilizing agent combinations, chemical recycle, and various parameters associated with sludge handling and disposal. The studies concluded that calcium hydroxide or aluminum sulfate could successfully remove color and produce a supernatant of suitable quality to recycle. The practicability of using coal-fired boiler flue gases to neutralize caustic wastewaters was demonstrated on full scale. Caustic wastewaters were used with a conventional wet scrubber to successfully neutralize the wastewaters by SO2 and CO2 absorption from the flue gas while simultaneously reducing the particulate emissions.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution, Textile Processes, Textiles, Waste Water, Neutralizing, Decoloring, Fly Ash, Adsorption, Sulfur, Flue Gases, Scrubbers, Sludge, Calcium Hydroxides, Aluminum Sulfate, Sulfur Dioxide, Carbon Dioxide	Pollution Control Stationary Sources Denim Chemical Destabilization	13B, 13H, 11E 07A/07D 21B, 07B

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 113
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE $5.50-2.25

EPA Form 2220-1 (9-73)

PRICES SUBJECT TO CHANGE

EPA-600/2-76-139
May 1976

TREATMENT OF DENIM TEXTILE MILL WASTEWATERS: NEUTRALIZATION AND COLOR REMOVAL

by

Charles R. Froneberger and Michael J. Pollock
R.S. Noonan, Inc. of South Carolina
Greenville, South Carolina

for

Canton Textile Mills, Inc.
P.O. Box 827
Canton, Georgia 30114

Grant No. S800852
ROAP No. 21AZT-006
Program Element No. 1BB036

EPA Project Officer: Thomas N. Sargent

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

EPA REVIEW NOTICE

This report has been reviewed by the U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policy of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

CONTENTS

Page

List of Figures iv

List of Tables vi

Acknowledgements ix

SECTIONS

I Conclusions 1

II Recommendations 3

III Introduction 5

IV Fly Ash Adsorption of Color 19

V Chemical Destabilization for Removal of Color 43

VI Neutralization of Caustic Wastewaters Utilizing Coal-Fired Boiler Flue Gases 63

VII References 89

VIII Appendix 93

FIGURES

Number		Page
1	Canton Textile Mills, Inc.'s manufacturing process flow diagram	7
2	Flow diagram of indigo dyeing process	8
3	Flow diagram of sulfur dyeing process	10
4	Flow diagram of Canton Textile Mills, Inc.'s existing wastewater treatment facility	14
5	Flow diagram of Canton Textile Mills, Inc.'s upgraded wastewater treatment facility	16
6	Canton Textile Mills, Inc.'s upgraded wastewater treatment facility	17
7	Fly ash adsorption isotherm with existing effluent	24
8	Fly ash adsorption isotherm with prefiltered effluent	25
9	Powdered activated carbon isotherm with prefiltered effluent	26
10	Gravity feed, packed-bed fly ash contacting flow diagram	27
11	Pressurized packed-bed fly ash contacting flow diagram	30
12	Pressurized packed-bed fly ash test apparatus	31
13	Expanded-bed fly ash contacting flow diagram	33
14	Buchner Funnel test apparatus	55
15	Filter leaf test apparatus	55
16	Flow diagram of treatment system with proposed chemical coagulation system addition	58
17	Neutralization pilot plant	68
18	Pilot plant effluent pH versus liquid/gas ratio	69
19	FMC/Link-Belt variable throat scrubber	73

FIGURES (Cont'd)

Number		Page
20	Process flow diagram of scrubber installation	74
21	Distant view of Canton Textile Mills, Inc.'s scrubber installation	75
22	Close-up view of Canton Textile Mills, Inc.'s scrubber installation	76
23	Percent SO_2 removal versus pH of scrubbing liquid	84

TABLES

Number		Page
1	Characterization of dye wastewaters	11
2	Typical profile of influent wastewater to the treatment system	12
3	Profile of existing treatment system's influent-effluent wastewater characteristics	13
4	Profile of upgraded treatment system's influent-effluent wastewater characteristics	18
5	Typical analysis of Canton Textile Mills' fly ash	20
6	Typical adsorption isotherm data	23
7	Typical results of fly ash packed-column tests with prefiltered effluent	29
8	Typical packed-bed fly ash test results	32
9	Results of fly ash expanded-bed test with prefiltered effluent	34
10	Fly ash slurry contact test results with unfiltered effluent	36
11	Fly ash slurry test results with prefiltered-effluent	37
12	Effect of pH on adsorption capacity of fly ash	38
13	Effect of temperature on the adsorption capacity of fly ash	39
14	Powdered activated carbon slurry contact results	40
15	Summary of phase one jar test investigations	46
16	Average results of successful jar tests on existing wastewater treatment plant effluent	47
17	Sludge characterization	48
18	Summary of alum sludge reduction investigations	49

TABLES (Cont'd)

Number Page

19 Typical results of alum regeneration-coagulation investigation 50

20 Relative economics of alum regeneration 51

21 Results of filter leaf tests with sludge generated from lime-Dow A-23 coagulation 56

22 Estimated capital costs of chemical coagulation system addition to Canton Textile Mills, Inc.'s existing biological treatment facility 59

23 Projected operating and maintenance costs of existing biological and new chemical coagulation system 60

24 Typical profile of existing stack gas 66

25 Wastewater characterization across pilot scrubber 71

26 Typical results of various scrubber operating conditions 79

27 Typical wastewater characterization across full scale scrubber 81

28 Comparative wastewater treatment characterization with and without scrubber neutralization of dyeing process wastewaters 83

29 Capital and operating costs of scrubber system 86

A1 Design data for existing wastewater facilities 94

A2 Design data for upgraded wastewater treatment facilities 95

A3 Packed column reactor test with unfiltered effluent 96

A4 Packed column reactor test with prefiltered effluent 97

A5 Typical jar test procedures 98

A6 Buchner Funnel test procedure 99

TABLES (Cont'd)

Number		Page
A7	Results of Buchner Funnel tests with sludge generated from alum coagulation	100
A8	Results of Buchner Funnel tests with sludge generated with lime coagulation	101
A9	Results of Buchner Funnel tests with sludge generated with magnesium carbonate and lime coagulation	102
A10	Results of Buchner Funnel tests with sludge generated with lime-Dow A-23 coagulation	103
A11	Typical coal analysis	104

ACKNOWLEDGEMENTS

The research reported herein is a combined effort of Canton Textile Mills, Inc. of Canton, Georgia and R. S. Noonan, Inc. of South Carolina, Greenville, South Carolina (Consulting Engineers).

The cooperation and assistance of Mr. T. E. Brumbeloe, Mr. J. C. Gray, Mr. J. T. Holbrook, Mr. L. G. Hobgood, and the maintenance staff of Canton Textile Mills, Inc., are gratefully acknowledged.

The cooperation of the FMC Corporation, the Duriron Company, Inc., and the Allis-Chalmers Company in providing equipment for the experimental scrubber phase of this project are gratefully acknowledged.

The technical assistance and support of the project by the United States Environmental Protection Agency and Mr. T. N. Sargent, the Grant Project Officer, are acknowledged with sincere thanks.

SECTION I

CONCLUSIONS

Over a forty-four month period, a study was conducted to investigate the use of fly ash adorption and chemical destabilization techniques of color removal from indigo and sulfur dyeing wastewaters. This investigation also included a feasibility study and subsequent full scale demonstration of coal-fired boiler flue gas wet scrubbing techniques for neutralization of caustic wastewaters.

Based on the results of these studies conducted at Canton Textile Mills, Inc., Canton, Georgia, the following conclusions have been reached:

1. The fly ash generated in Canton Textile Mills, Inc.'s coal-fired boiler is capable of adsorption and subsequent removal of color, BOD_5, and COD from the biologically treated domestic and dyeing process wastewaters. The adsorption capacity, however, is significantly below that of powdered activated carbon.

2. The use of column reactors (expanded or packed-bed) for fly ash-wastewater contact was found to be impractical due to problems related to hydraulic plugging and channeling of flow resulting from the extremely fine fly ash and the suspended solids present in the wastewater.

3. The use of slurry fly ash contacting reactors was also demonstrated impractical due to the volume of fly ash required in excess of that produced at the mill to achieve a significant color reduction of the wastewaters.

4. Chemical destabilization of the effluent from the existing biological treatment system was demonstrated to have the ability of accomplishing removal of color and the production of a supernatant of suitable quality to recycle.

5. Of eleven destabilizing agent combinations investigated, it was proven that alum or lime with an anionic polyelectrolyte could successfully accomplish removal of color and the production of a supernatant suitable to recycle.

6. Lime-polyelectolyte coagulation illustrated the ability of producing a sludge with good dewatering characteristics which was amenable to dewatering with conventional vacuum filtration techniques. The chemical and disposal costs associated with the lime dosages required were, however, considered economically impractical for present application.

7. Economically, the use of alum coagulation has the potential of resulting in a significant savings in chemical cost over that of the lime-polyelectrolyte coagulant cost. The economic advantage of alum, however, is contingent upon the cost associated with that of overcoming the poor dewatering properties of the alum sludge. The alum sludge was not considered to be capable of conventional vacuum filtration techniques without further proper conditioning.

8. The practicability of utilizing coal-fired boiler flue gases to neutralize caustic wastewaters was demonstrated. Caustic wastewaters were used in conjunction with a conventional wet scrubber to successfully neutralize the wastewaters by carbon dioxide and sulfur dioxide absorption from the flue gas while simultaneously reducing the particulate emissions.

9. Neutralization of the wastewaters by flue gas scrubbing appeared to improve the efficiency of the subsequent biological treatment system by producing a more favorable pH and alkalinity while producing relatively insignificant other detrimental effects upon the wastewater.

SECTION II

RECOMMENDATIONS

1. As a result of the laboratory chemical destabilization investigations, it is recommended that future efforts in this area should be directed into the use of alum coagulation.

2. Further investigation of alum coagulation should be concentrated on improving the sludge dewatering characteristics. It is recommended that additional polyelectrolytes and suitable sludge conditioners be investigated to improve the amenability of alum sludge to conventional vacuum filtration techniques. Other dewatering techniques such as the cyclone or various gravity-type filters should also be investigated.

3. If the investigations, as recommended in 1 and 2 above, prove successful, it is further recommended that the alum coagulation evaluation be extended to a pilot scale study to provide indicative chemical cost and operational data for a continuous flow system. Consideration should also be given at this time to the possible use of the scrubber installation for producing the optimum pH levels required for alum coagulation. This could result in a significant economic savings in a full scale installation.

SECTION III

INTRODUCTION

High pH and color are often typical characteristics of textile dyehouse wastewaters. In addition to the complexity of wastewater treatment problems, mills presently operating coal-fired boilers or those faced with the conversion to coal as a result of fuel shortages, are now confronted with tasks of meeting compliance regulations related to the control of noxious gases and particulate emissions. The intent of this research project was to investigate an integrated solution to both of these problems. The approach was to combine dye wastewaters and combustion by-products of coal to offset the less desirable effects of each by utilizing the causticity of the dyehouse wastewater and the neutralizing capacity of the scrubbed flue gases.

Included in this report are the results of a forty-four month research project initiated jointly by Canton Textile Mills, Inc. of Canton, Georgia and the United States Environmental Protection Agency under EPA Grant S800852. The objectives of the research project as proposed were as follows:

1. Investigate the practicability of utilizing the caustic wastewaters resulting from the dyeing processes, as a scrubbing agent in conventional scrubber equipment to accomplish a reduction of the particulate matter and noxious gases in the flue gas while neutralizing the wastewater causticity.
2. Investigate the potential of using the residual carbon adsorption value of the fly ash generated from the combustion of coal for the adsorption and subsequent removal of the color producing dyes from the wastewater.
3. Investigate the feasibility of utilizing the fly ash as a filtration media to remove suspended solids from the wastewater while simultaneously removing color by adsorption.
4. Utilize the treatment concepts listed in 1, 2, and 3 above in conjunction with a conventional biological wastewater treatment system to produce a final wastewater quality suitable for recycle to the dyeing process.

The research project was performed in two phases. The initial phase, including bench scale and pilot testing, was conducted to provide design information for a full scale application. Early in the bench scale investigation of the fly ash adsorption of color, it was concluded that this technique of color removal was impractical for this application. As a result, the scope of the project was redefined to include an evaluation of the feasibility of utilizing chemical destabilization techniques of color removal from the dyehouse wastewaters.

Preceding page blank

The second phase consisted of a demonstration of the full scale scrubber installation as an integral part of the mill's total wastewater treatment facility.

Simultaneously with the EPA Research and Demonstration Grant, Canton Textile Mills, Inc. initiated a program to upgrade the existing biological treatment system in order to obtain compliance with the Georgia Department of Natural Resources' wastewater treatment regulations. This necessitated several major modifications to the existing treatment facility. These modifications are described within this report. Due to the time factor involved in upgrading the existing biological system (i.e., preliminary field engineering, submittal of plans for state approval, final design engineering, equipment purchase, and construction), the bench scale phase of the fly ash adsorption research was conducted concurrently with this work. Therefore, to accomplish the bench scale fly ash investigations, it was necessary to simulate the expected improvement in the effluent. This was attempted by simply screening or filtering the existing system's effluent to reduce the concentration of suspended solids.

The research reported herein is a combined effort of Canton Textile Mills, Inc., of Canton, Georgia and R. S. Noonan, Inc. of South Carolina, Greenville, South Carolina, (Consulting Engineers).

PROJECT SITE

The site of the project is Canton Textile Mills, Inc.'s Mill No. 2 in Canton, Georgia. This facility produces an average of 60,000 to 80,000 pounds of finished cotton denim fabric per day with a normal seven-day, 24-hour per day, mill production week and a 5-day per week dyehouse production week.

Manufacturing Process Description

A number of mechanical operations have to be performed to convert cotton fibers into fabrics. The operations performed at this facility to produce fabric are shown in the flow diagram listed as Figure 1. Although several of these processes are wet operations, the primary contributor in terms of pollution load and volume of wastewater is the dyeing operation. Indigo and sulfur dyeing processes are utilized at the mill.

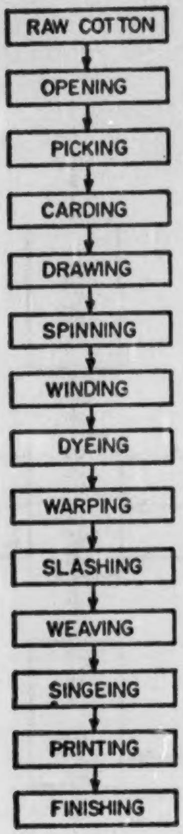
RAW COTTON
OPENING
PICKING
CARDING
DRAWING
SPINNING
WINDING
DYEING
WARPING
SLASHING
WEAVING
SINGEING
PRINTING
FINISHING

Figure 1. Canton Textile Mills, Inc.'s manufacturing process flow diagram

Due to the larger number of aqueous rinses, the indigo dyeing process is the major contributor of wastewater in terms of volume. A flow diagram of the indigo process is provided in Figure 2. Dry cotton warp fibers enter a wetting out bath containing a penetrant. The warp fibers are then rinsed with cold water and processed through a series of five indigo dye vats containing indigo reduced with sodium hydrosulfite and caustic soda. Following each addition of indigo dye, the fiber is oxidized in air. Once the dyeing cycle is completed, the dyed cotton fibers are given an additional three stage wash consisting of cold, warm, and hot water baths and dried.

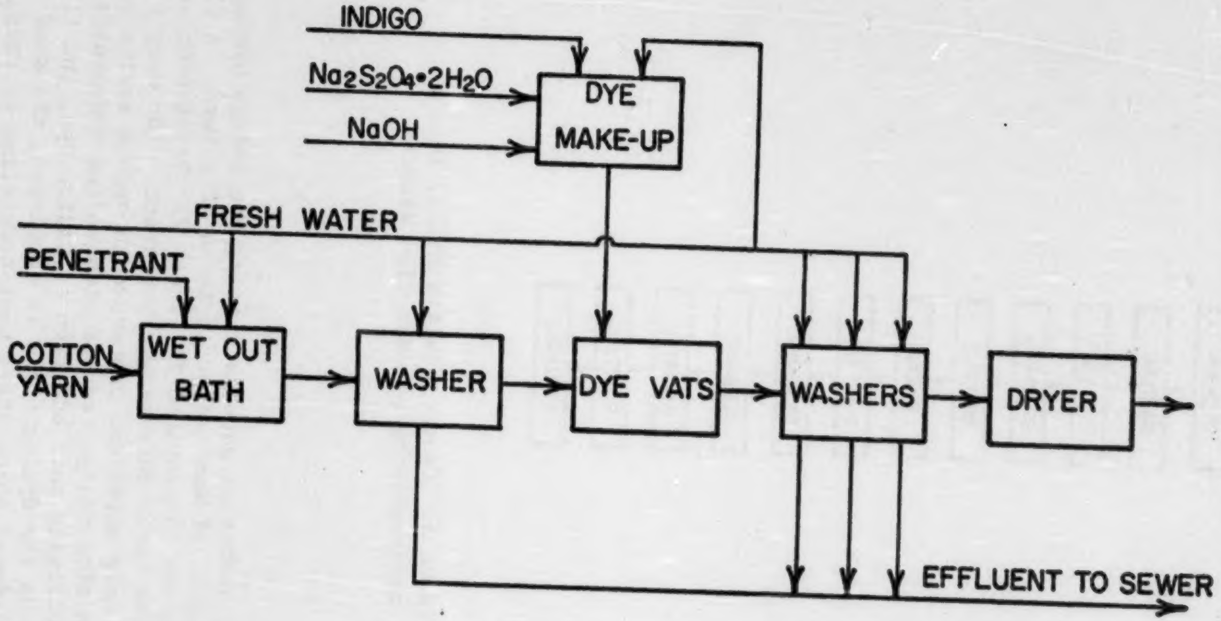
INDIGO
Na2S2O4•2H2O
NaOH
DYE MAKE-UP
FRESH WATER
PENETRANT
COTTON YARN
WET OUT BATH
WASHER
DYE VATS
WASHERS
DRYER
EFFLUENT TO SEWER

Figure 2. Flow diagram of indigo dyeing process.

The sulfur or commonly called sulfur-black process consists of two separate types of dye applications as illustrated in Figure 3. In this process, the sulfur-black dye is applied in the initial vat along with a formulation of soluble oil, penetrant, and sodium sulfite which is part of the purchased dye. A cold water wash follows the sulfur dye vat after which the warp enters a single stage indigo dye bath and is oxidized in air. The indigo vat contains indigo dyestuff, sodium hydroxide, sodium hydrosulfite and dextrose. The fiber is finally rinsed twice, once with cold water and once with hot water, and dried. Occasionally, this dye range is utilized for varying types of sulfur and naphthol colors with diluted hydrogen peroxide used in oxidizing the various colors. The relative use of the different dyes varies with production requirements.

During the latter stages of this project (in January 1975), the sulfur dye range was modified to reverse the points of indigo and sulfur dye applications. This was done to produce a more desirable color in the final product. This change also significantly reduced the quantity of sulfur dye used and as a result, altered the wastewater characteristics somewhat. This process change had no direct bearing on the major portion of the project except in evaluating the effect of scrubber neutralization. Further discussion has, therefore, been restricted to that portion of this report.

Wastewater Characterization

The wastewaters resulting from the dyeing processes contribute a major portion of the total volume of wastewater to the mill's treatment facility. During production periods, this wastewater stream ranges from 570 to 850 liters per minute (150-225 gpm). Normal daily production time for each dye unit varies greatly from day to day, ranging from 10 to 24 hours. The wastewater from each of the dyeing units (indigo and sulfur) is characterized in Table 1.

The dyeing process wastewaters combine with three additional wastewaters—sanitary sewage from the mill and a nearby residential area (96 liters/minute) and the discharge from a local hospital (36 liters/minute)—to form a total average weekday volume of 1037 cubic meters (274,000 gallons). Because of the mill's five-day dyehouse production schedule, the weekend flow drops off significantly to an average of 273 cubic meters (72,000 gallons) per day and is almost entirely domestic sewage and hospital wastes. A profile of the typical weekday and weekend wastewater characteristics is provided in Table 2.

Because the major portion of the total wastewater volume results from the dyeing processes, the influent wastewater characteristics often vary quite dramatically as a result of frequent production variations. In addition to flow variations resulting from production trends, the influent is influenced by apparent rainwater infiltration. This is quite obvious from the heavy influent flow rates observed during rainy periods.

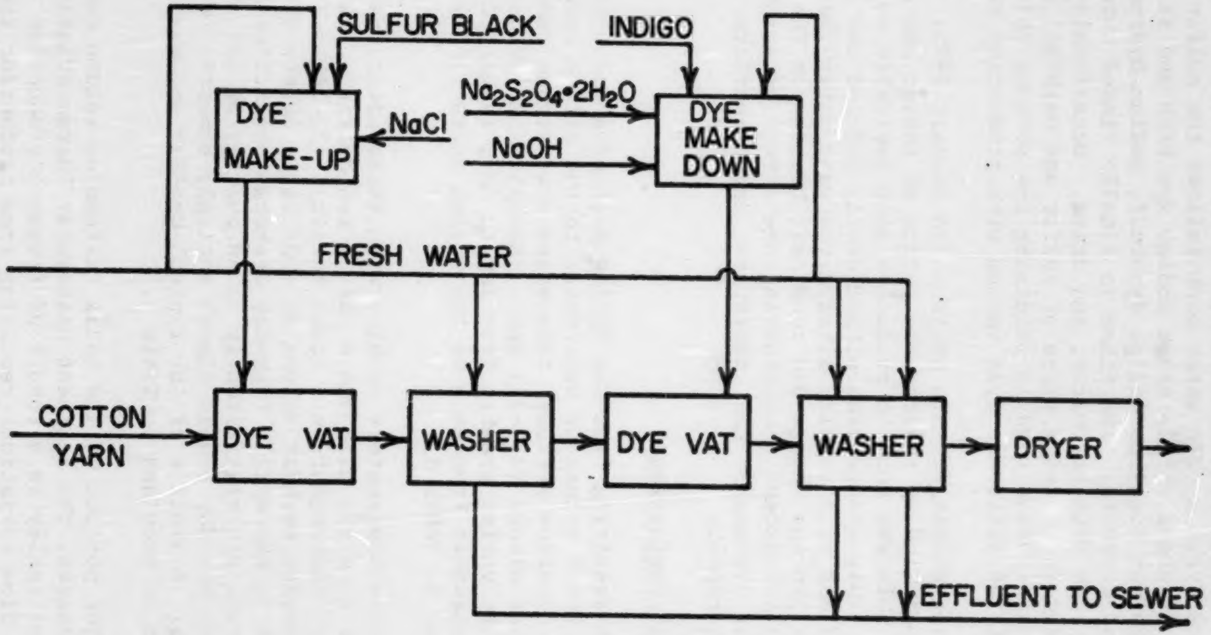
SULFUR BLACK
INDIGO
DYE MAKE-UP
NaCl
$Na_2S_2O_4 \cdot 2H_2O$
NaOH
DYE MAKE DOWN
FRESH WATER
COTTON YARN
DYE VAT
WASHER
DYE VAT
WASHER
DRYER
EFFLUENT TO SEWER

Figure 3. Folw diagram of sulfur dyeing process.

Table 1. CHARACTERIZATION OF DYE WASTEWATERS

Parameter	Units	Indigo Range	Sulfur Range	Modified Sulfur Range[a]
Temperature	°C	40	60	60
pH	Units	10.5-11.5	10-11	10-11
Color	APHA Pt.-Co.	5500-7500	24000-34000	-
COD	mg/1	750-950	2500-3500	500-1700
BOD	mg/1	400-750	900-1350	400-750
TOC	mg/1	150-300	-	300-500
Total Solids	mg/1	2500-3300	-	1600-3400
Suspended Solids	mg/1	50-300	100-340	200-450
Iron	mg/1	0.10-0.5	-	1-1.3
Zinc	mg/1	0.05-0.10	-	0.3-0.5
Calcium	mg/1	9-13	-	6-11
Magnesium	mg/1	4-7	-	4-8

[a] Wastewater resulting from the reversal of the sulfur and indigo dye application points. This change took place in January, 1975 at which time the fly ash adsorption and chemical coagulation studies had been completed.

Table 2. TYPICAL PROFILE OF INFLUENT WASTEWATER TO THE TREATMENT SYSTEM

Parameter	Units	Weekday Influent[a]	Weekend Influent[a]
Flow	lpm	720	190
Temperature	°C	25-40	14-18
Dissolved Oxygen	mg/l	2-5	5-8
pH	Units	10.0-11.5	6.0-7.5
p Alkalinity	mg/l as $CaCO_3$	150-350	-
m Alkalinity	mg/l as $CaCO_3$	400-900	50-150
Acidity	mg/l as $CaCO_3$	-	10-40
Color	APHA Pt. Co.	2800-10,000	400-5000
COD	mg/l	500-1800	300-600
BOD	mg/l	300-500	100-300
TOC	mg/l	250-400	80-150
Zinc	mg/l	0.2-1.9	0.1-0.3
Chromium	mg/l	0.1-0.4	0.5-0.09
Copper	mg/l	0.05	0.05
Iron	mg/l	0.7-1.8	0.7-1.4
Phosphate, Total	mg/l	5-8	6-8
Nitrogen, Total Kjeldahl	mg/l	5-30	15-30
Total Solids	mg/l	1600-3700	400-800
Total Volatile Solids	mg/l	400-800	100-200
Suspended Solids	mg/l	80-230	60-130
Dissolved Solids	mg/l	600-2200	250-350

[a] Average results of analyses performed on 24-hour composite samples.

Existing Biological Treatment System

The mill's biological treatment facility, as it existed at the beginning of the research project, is shown in Figure 4. Constructed in 1960, this system consisted of screening, preaeration, extended aeration activated sludge, and clarification. Flow monitoring was accomplished at an influent parshall flume. Due to the extended aeration nature of the activated sludge process, the system relied on complete oxidation to prevent sludge accumulation. More specific design data for this system is provided in the Appendix in Table A1.

The results of a routine weekly influent-effluent wastewater monitoring program conducted during the period of May 1971 through May 1973 are summarized in Table 3. As may be observed from this data, the existing treatment system was characterized by frequent upsets in operation leading to poor treatment efficiencies. The instability of the treatment system was attributed to large variations in flow and frequent changes in the influent wastewater chemical characteristics (e.g., BOD, COD, and pH).

Table 3. PROFILE OF EXISTING TREATMENT SYSTEM'S INFLUENT-EFFLUENT WASTEWATER CHARACTERISTICS[a]

Parameter	Units	Influent @ Parshall Flume Ave.(Std. Deviation)	Effluent @ Clarifier Overflow Ave.(Std. Deviation)	Average Removal %
BOD_5	mg/l	429 (244)	163 (88)	62
COD	mg/l	1045 (474)	547 (339)	48
Total Solids	mg/l	1808 (595)	1071 (365)	41
Suspended Solids	mg/l	230 (89)	190 (96)	27
pH	Units	10.3 (1.0)	7.8 (0.9)	-

[a] Data taken from routine weekly monitoring - May, 1971 through May, 1973.

NOTE: This data was taken on weekdays only and does not reflect weekend characteristics.

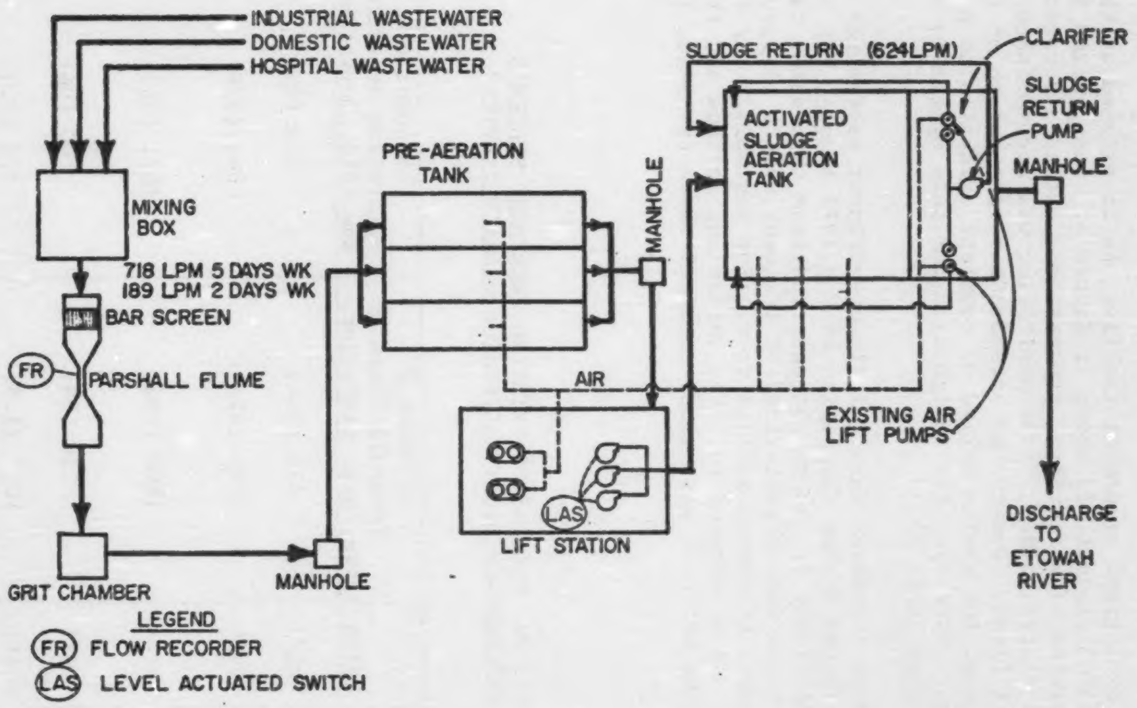
INDUSTRIAL WASTEWATER
DOMESTIC WASTEWATER
HOSPITAL WASTEWATER
MIXING BOX
718 LPM 5 DAYS WK
189 LPM 2 DAYS WK
BAR SCREEN
FR
PARSHALL FLUME
GRIT CHAMBER
MANHOLE
PRE-AERATION TANK
MANHOLE
AIR
LAS
LIFT STATION
SLUDGE RETURN (624LPM)
ACTIVATED SLUDGE AERATION TANK
CLARIFIER
SLUDGE RETURN PUMP
MANHOLE
EXISTING AIR LIFT PUMPS
DISCHARGE TO ETOWAH RIVER
LEGEND
FR FLOW RECORDER
LAS LEVEL ACTUATED SWITCH

Figure 4. Flow diagram of Canton Textile Mills, Inc.'s existing wastewater treatment facility

Upgraded Treatment System

In order to obtain compliance with the Georgia Department of Natural Resources' treatment requirements, Canton Textile Mills, Inc. initiated a program to upgrade the existing biological treatment system. At the date of the upgrading of the existing facility, the State of Georgia's Department of Natural Resources specified a treatment equivalent to secondary treatment which is defined as approximately eighty-five percent (85%) removal of the five-day Biochemical Oxygen Demand[1].

The first step in upgrading the existing treatment system was to bring the system to its highest attainable level of operating efficiency. During a special maintenance period, all pipes were flushed, excess grit and sludge were removed from tanks, air spargers were cleaned, and adjustments made to the clarifier weir. In addition, a daily operational log was initiated so that performance trends could be observed and operational adjustments made if necessary.

Although the clean-up and operational changes greatly improved the efficiency of the system, it was concluded that three major modifications would be necessary to obtain reliable treatment levels on a daily basis. First, the flow from the grit chamber was diverted to a newly constructed equalization pond with a nominal capacity of $3785 m^3$ (1,000,000 gallons). The purpose of this pond was to dampen flow fluctuations and protect the biomass from shock organic loads resulting from the mill's production variations. The second modification consisted of providing additional clarification, increased sludge recycle capabilities, and provisions for sludge wasting and aerobic digestion. Provisions were made in the selection of new clarifier and aerobic digester to allow those units to be utilized in a future chemical coagulation system if such a system proved feasible. The third addition to the system provided for the chlorination of the final effluent. A flow diagram of the upgraded system is provided in Figure 5 and a photograph of the system is provided in Figure 6 with more specific design data tabulated in the Appendix in Table A2.

The upgrading work was completed in May, 1974. The results of a seven-day monitoring program provided in Table 4 shows the typical treatment efficiencies resulting from this program. The effect of equalization is readily apparent as shown by the reduced standard deviations of the wastewater's characteristics. The high concentration of suspended solids in the effluent is attributed to the presence of colloidal suspensions of dye which are not biologically destabilized.

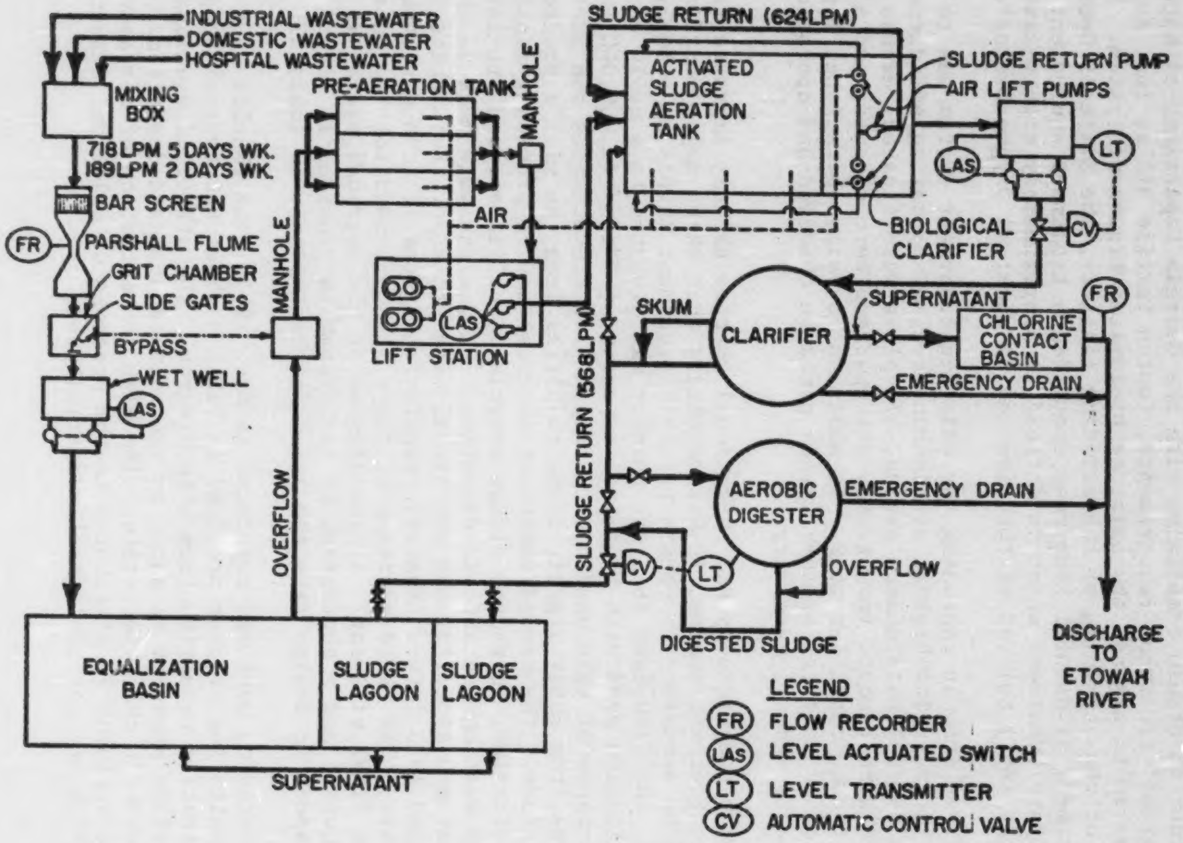
INDUSTRIAL WASTEWATER
DOMESTIC WASTEWATER
HOSPITAL WASTEWATER
MIXING BOX
718 LPM 5 DAYS WK.
189 LPM 2 DAYS WK.
BAR SCREEN
FR
PARSHALL FLUME
GRIT CHAMBER
SLIDE GATES
BYPASS
WET WELL
LAS
MANHOLE
OVERFLOW
PRE-AERATION TANK
MANHOLE
AIR
LIFT STATION
LAS
SLUDGE RETURN (624LPM)
ACTIVATED SLUDGE AERATION TANK
SLUDGE RETURN PUMP
AIR LIFT PUMPS
LAS
LT
CV
BIOLOGICAL CLARIFIER
SKUM
CLARIFIER
SUPERNATANT
FR
CHLORINE CONTACT BASIN
EMERGENCY DRAIN
SLUDGE RETURN (568LPM)
AEROBIC DIGESTER
EMERGENCY DRAIN
OVERFLOW
CV
LT
DIGESTED SLUDGE
DISCHARGE TO ETOWAH RIVER
EQUALIZATION BASIN
SLUDGE LAGOON
SLUDGE LAGOON
SUPERNATANT
LEGEND
FR FLOW RECORDER
LAS LEVEL ACTUATED SWITCH
LT LEVEL TRANSMITTER
CV AUTOMATIC CONTROL VALVE

Figure 5, Flow diagram of Canton Textile Mills, Inc.'s upgraded wastewater treatment facility

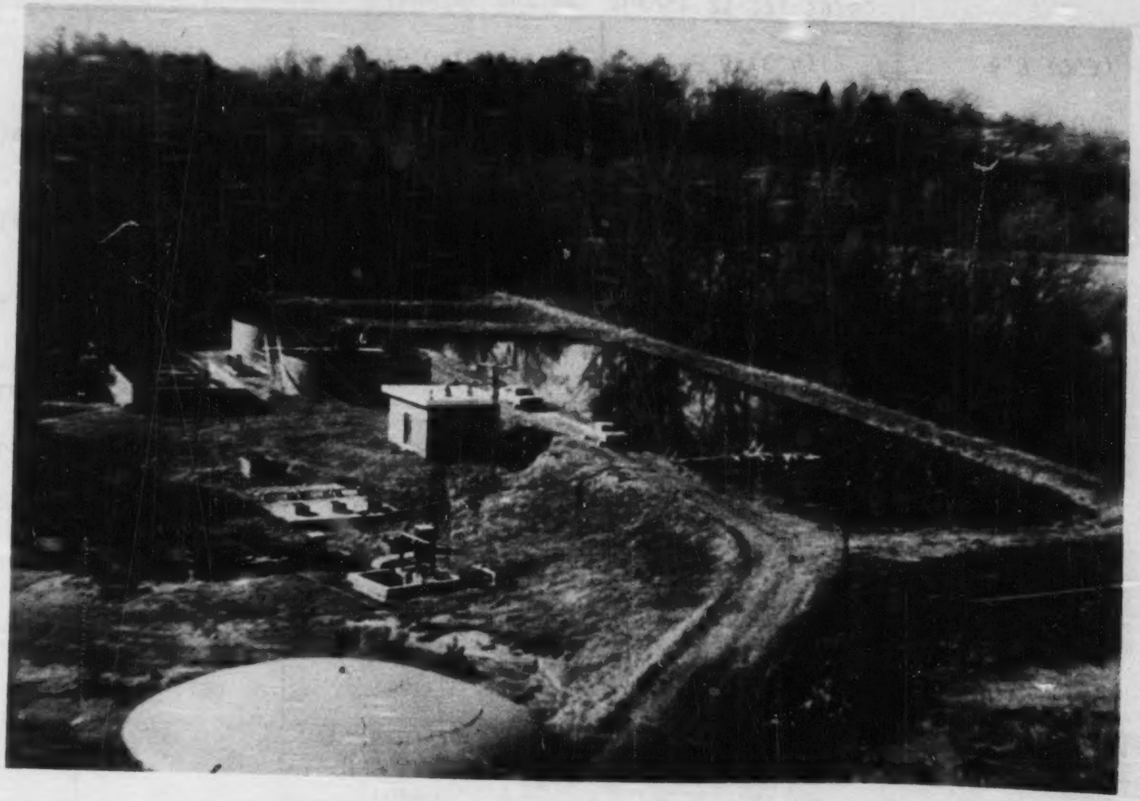

Figure 6. Canton Textile Mills, Inc.'s upgraded wastewater treatment facility

Table 4. PROFILE OF UPGRADED TREATMENT SYSTEM'S INFLUENT-EFFLUENT WASTEWATER CHARACTERISTICS[a]

Parameter	Units	Influent @ Parshall Flume[b] Ave.(Std. Deviation)	Equalization Pond Effluent Ave.(Std. Deviation)	Final Effluent Ave.(Std. Deviation)	Removal %
BOD_5	mg/l	392 (158)	394 (85)	42 (14)	89
COD	mg/l	884 (266)	931 (38)	284 (72)	68
TOC	mg/l	241 (62)	238 (26)	92 (29)	62
Alkalinity, M	mg/l as $CaCO_3$	431 (168)	422 (33)	209 (30)	-
Total Solids	mg/l	1880 (579)	1930 (124)	1634 (102)	13
Total Volatile Solids	mg/l	570 (162)	492 (97)	254 (68)	-
Suspended Solids	mg/l	129 (66)	171 (30)	175 (50)	-
Susp. Volatile Solids	mg/l	100 (43)	131 (23)	181 (90)	-
Settleable Solids	mg/l	-	-	0.1	-
pH	Units	10.0 (0.7)	8.6 (0.4)	6.9 (0.3)	-

[a] Data was taken during seven-day monitoring period, August 21-27, 1974.

[b] To allow comparison with previous data, influent averages are for weekdays only.

SECTION IV

FLY ASH ADSORPTION OF COLOR

One of the major problems resulting from the combustion of coal is the disposal of the combustion by-product, fly ash. Due to the ever-increasing demand for cleaner air, the quantity of fly ash recovered from the combustion of coal in furnace - boiler systems has increased appreciably over the recent years. The disposal of this fly ash has now become an acute solid waste problem[2].

It has recently been reported that less than ten percent (10%) of the fly ash generated in the United States is utilized to any degree[3]. Efforts to utilize or at least recover disposal costs have been primarily directed towards utilization of the pozzolanic properties of fly ash for a constituent in concrete and concrete products[4]. One area that has recently gained recognition involves the utilization of fly ash as an adsorbent material[5].

Due to the residual carbon value of fly ash and its relatively large surface area per unit volume, fly ash exhibits many of the adsorbent characteristics of activated carbon[2]. Fly ash has been reported in the literature to be an effective adsorbent for the removal of various chemical constituents such as refractory organic materials[6], phenols[7], and color resulting from various soluble organic materials found in polluted lake waters[5]. It is this adsorption characteristic that was used as the basis for the investigation of fly ash as a mechanism of color removal from the wastewaters of Canton Textile Mills, Inc.

PROPERTIES OF FLY ASH

Fly ash consists of a heterogeneous material consisting of minute particles of inert compounds and partially burned carbon particles generally ranging in size from 0.5 to 300 microns. Chemically, fly ash consists of unburned carbon and a variety of oxides - aluminum, magnesium and sulfur - as well as other trace metals. The physical size and shape of fly ash particles is largely determined by the type of coal, type of firing equipment, and even the type of collection system employed.

The source of fly ash used for the research was obtained from Canton Textile Mills, Inc.'s 27.2 metric ton per hour (60,000 pounds per hour) spreader stoker-fired boiler (Combustion Engineering, Inc.'s C-E Vertical Unit). This installation utilizes a Whirlex dust collector to remove approximately 34 to 45 kilograms (75 to 100 lbs.) of fly ash per hour. A typical analysis of this fly ash is provided in Table 5.

Table 5. TYPICAL ANALYSIS OF
CANTON TEXTILE MILLS' FLY ASH

Chemical Composition	By Weight (%)
Silica, SiO_2	19.72
Alumina, Al_2O_3	22.03
Iron Oxide, Fe_2O_3 or Fe_3O_4	6.00
Calcium Oxide, CaO	1.72
Magnesium Oxide, MgO	1.11
Sulfur Trioxide, SO_3	0.63
Loss on Ignition, Carbon	46.21
Trace Elements (By Difference)	2.58
Physical Properties	**By Weight (%)**
Range of Particle Size, Microns	0.5-2500
Ave. % Passing No. 325 Sieve (U. S. Standard)	21
Bulk Density, gm/cc	0.47
Specific Gravity, gm/cc	2.0

LABORATORY INVESTIGATION

The objective of the laboratory investigation was to evaluate fly ash as an adsorption media for the removal of color from Canton Textile Mill, Inc.'s wastewaters. Over one hundred tests were performed to determine optimum parameters for a full scale fly ash color removal system. These tests investigated various contacting systems - batch, packed-bed, and expanded-bed as well as the effects of pH and temperature on the adsorption capacity.

Adsorption Isotherms

Prior to initiating the investigation of the various fly ash - wastewater contacting systems, a series of jar tests was conducted in order to develop adsorption isotherms. An adsorption isotherm is simply a plot showing the relationship between the amount of impurities (color) adsorbed on a unit weight of adsorption media (fly ash) and the amount of impurities (color) remaining in the wastewater. These isotherms are useful in:

1. Providing a general indication of the effectiveness of the adsorption media.

2. Predicting the maximum quantity of impurities (color) capable of being adsorbed onto the media.

The adsorption isotherms were developed by placing various quantities of fly ash in each of several jars containing a constant volume and concentration of dye wastewaters. The jars were then shaken simultaneously for a period of thirty minutes by a mechanical shaker with the supernatant color measured both before and after agitation. The adsorption capacity was then expressed as an adsorption isotherm in accord with the Freundlich Equation[8]. The Freundlich Equation has the general form:

$$x/m = k\,C_R^{\,n} \qquad (01)$$

where x = Amount of residual color reduction due to adsorption ($C_I - C_R$), APHA Pt. Co.

m = Mass Concentration of the Fly Ash, gm/l

k = Constant (obtained from graphical plot)

n = Constant (obtained from graphical plot)

C_R= Residual Color of Adsorbate at Equalibrium Expressed in APHA Pt. Co.

C_I= Initial Color (APHA Pt. Co.)

It is usual practice to take logarithms of both sides of the above expression to obtain:

$$\log x/m = \log k + n \log C_R \qquad (02)$$

Therefore, a plot of log (x/m) vs. log (Cr) will be a straight line with a slope of "n" and an intercept of "log k". This data was then used in predicting fly ash requirements for single batch treatment and column systems.

The isotherm plot was also used to provide an indication of the theoretical adsorption capacity. The adsorption capacity was determined by entering the abscissa with the initial color concentration (C_O) and obtaining the color reduction per mass concentration of fly ash (x/m) at the intersection of the isotherm plot.

In the investigation, adsorption isotherms were determined utilizing the final effluent from the mill's biological treatment facility. Three typical isotherms are shown using the following variations:

1. Isotherm No. 1 was developed with the treatment plant's final effluent and with fly ash from the mill's coal-fired boiler.

2. Isotherm No. 2 was derived with the final effluent prefiltered through a 12-inch deep sand filter for suspended solids removal and again with the mill's fly ash.

3. Isotherm No. 3 was determined utilizing the sand filtered effluent and Westvaco's Aqua Nuchar A powdered activated carbon.

The results of these investigations are tabulated in Table 6 with the corresponding graphical plots provided in Figures 7 - 9.

The results of the adsorption isotherm investigations led to the following conclusions:

1. Fly ash was capable of removing the color constituent from the wastewaters.

2. Removal or reduction of suspended solids appears to enhance the ability of the fly ash to adsorb color as is observed in the increased adsorbance capacity.

3. The results of the isotherm test indicate that the fly ash requirements to achieve an effluent color of less than 100 APHA Pt. Co. color units will be significantly larger than the fly ash available from the mill's boiler. By utilizing the Freundlich Equation and the constants developed in the isotherm plots (Figures 7 - 9), it is predicted that 61 gm of fly ash will be required per liter of unfiltered wastewater to reduce the color from 440 to 100 APHA Pt. Co. Units while 23 gm of fly ash will be required per liter of the filtered effluent for a similar color reduction. These values drastically exceed the quantity of fly ash available from the mill's boiler per unit volume of wastewater which is 0.8 gm/l.

4. Comparatively, powdered activated carbon exhibits a superior adsorption capacity to that of fly ash. By use of the Freundlich Equation and data developed in the isotherm plot (Figure 8), it is predicted that only 2 gm of activated carbon will be required per liter of filtered effluent to achieve an effluent with a color level of 100 APHA Pt. Co. Units. Therefore, it appears that the fly ash is only approximately 10 percent as effective as the powdered activated carbon in achieving color removal.

Packed-Bed Contacting Systems

The first of the bench scale investigations of the various contacting systems were performed with the test apparatus illustrated in Figure 10. This system consisted of a 5.72cm I.D. (2.25 inch I.D.) plexiglass, gravity feed column containing varying amounts of fly ash. Wire mesh screen was used at both fly ash interfaces of the column to retain the fly ash. A constant liquid level was maintained in the overhead feed tank through the use of a sump pump controlled by a level switch.

Table 6. TYPICAL ADSORPTION ISOTHERM DATA

Isotherm No. 1[a] (raw effluent and boiler fly ash)

Fly Ash Dosage (m) (gm/liter of wastewater)	Residual Color (C_R) (APHA Pt. Co. Units)	Color Removed (x) ($X = C_I - C_R$)	x/m
0	440	-	-
5	400	40	8.0
20	150	290	14.5
60	125	315	5.2
100	25	415	4.2
170	5	435	2.6

Isotherm No. 2[b] (prefiltered effluent and boiler fly ash)

Fly Ash Dosage (m) (gm/liter of wastewater)	Residual Color (C_R) (APHA Pt. Co. Units)	Color Removed (x) ($X = C_I - C_R$)	x/m
0	440	-	-
2.50	400	40	16.0
3.75	390	50	13.4
5.00	370	70	14.0
10.00	300	140	14.0
25.00	60	380	15.2

Isotherm No. 3[c] (prefiltered effluent and Westvaco's Aqua Nuchar A Powdered Activated Carbon)

Act. Carbon Dosage (m) (gm/liter of wastewater)	Residual Color (C_R) (APHA Pt. Co. Units)	Color Removed (x) ($X = C_I - C_R$)	x/m
0	420	-	-
1.25	180	240	192.0
2.50	30	390	156.0
3.75	10	410	109.0
5.00	0	420	84.0
10.00	0	420	42.0

[a] Refer to Figure 7 for graphical plot.

[b] Refer to Figure 8 for graphical plot.

[c] Refer to Figure 9 for graphical plot.

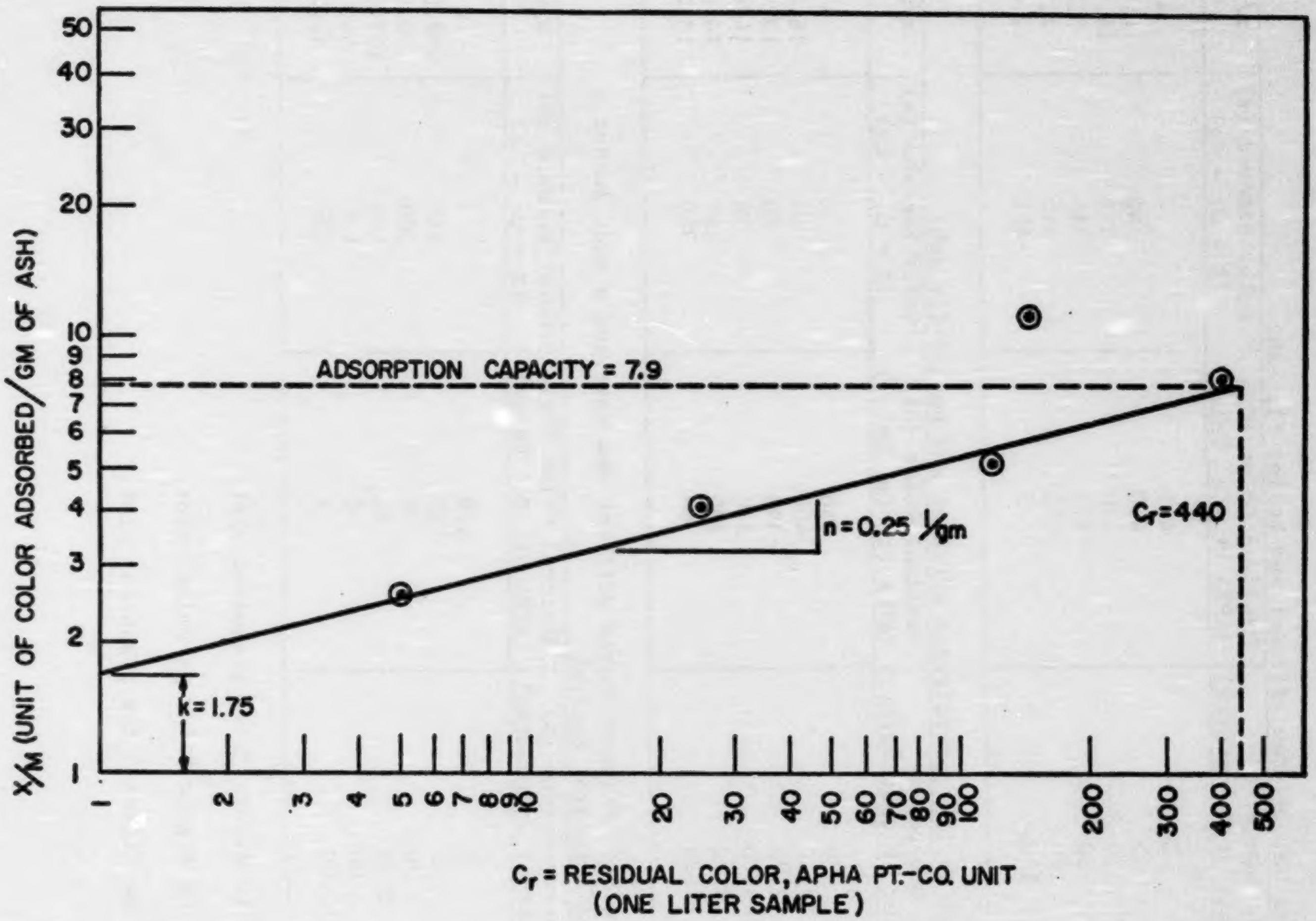

Figure 7. Fly ash adsorption isotherm with existing effluent.

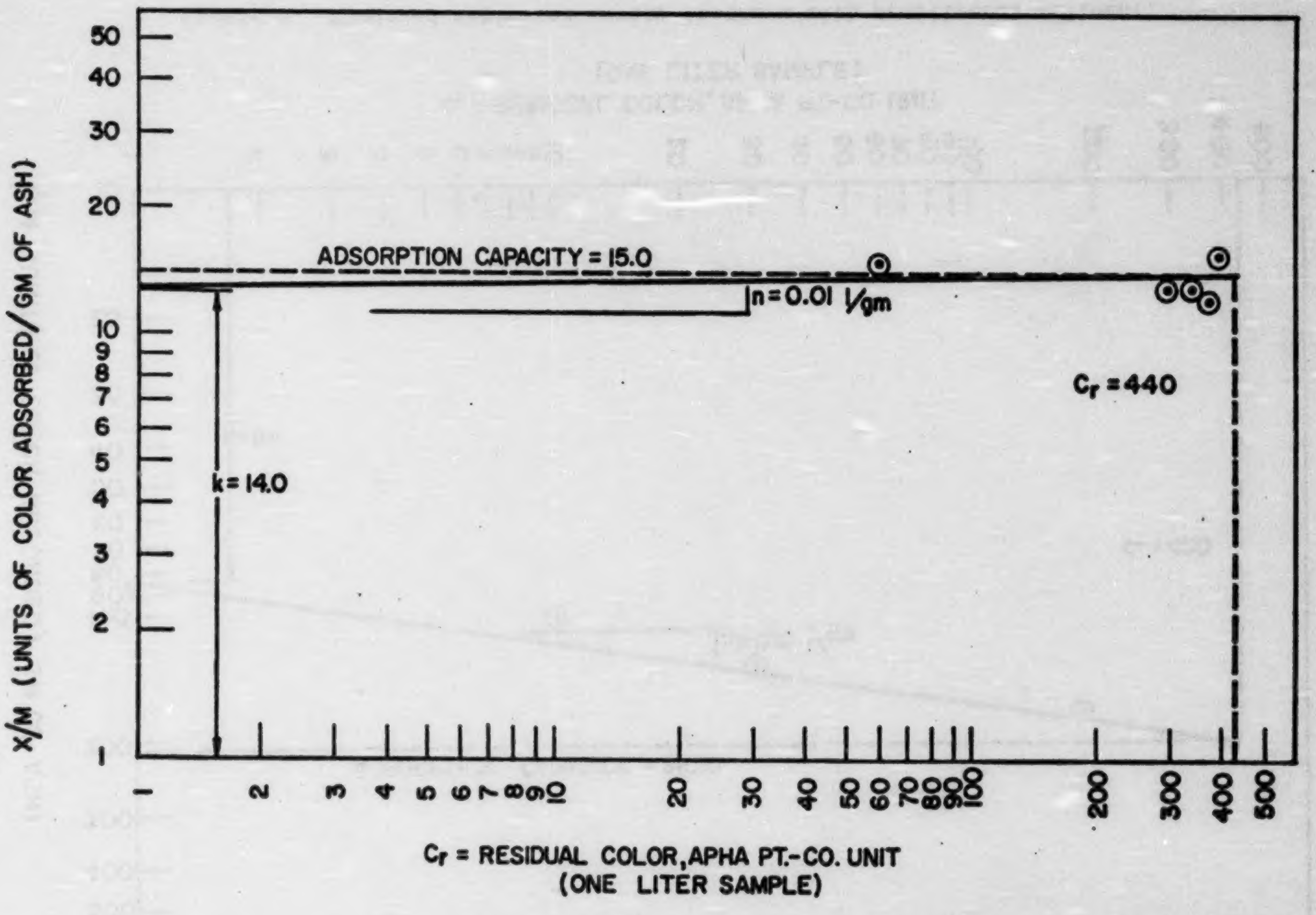

Figure 8. Fly ash adsorption isotherm with prefiltered effluent.

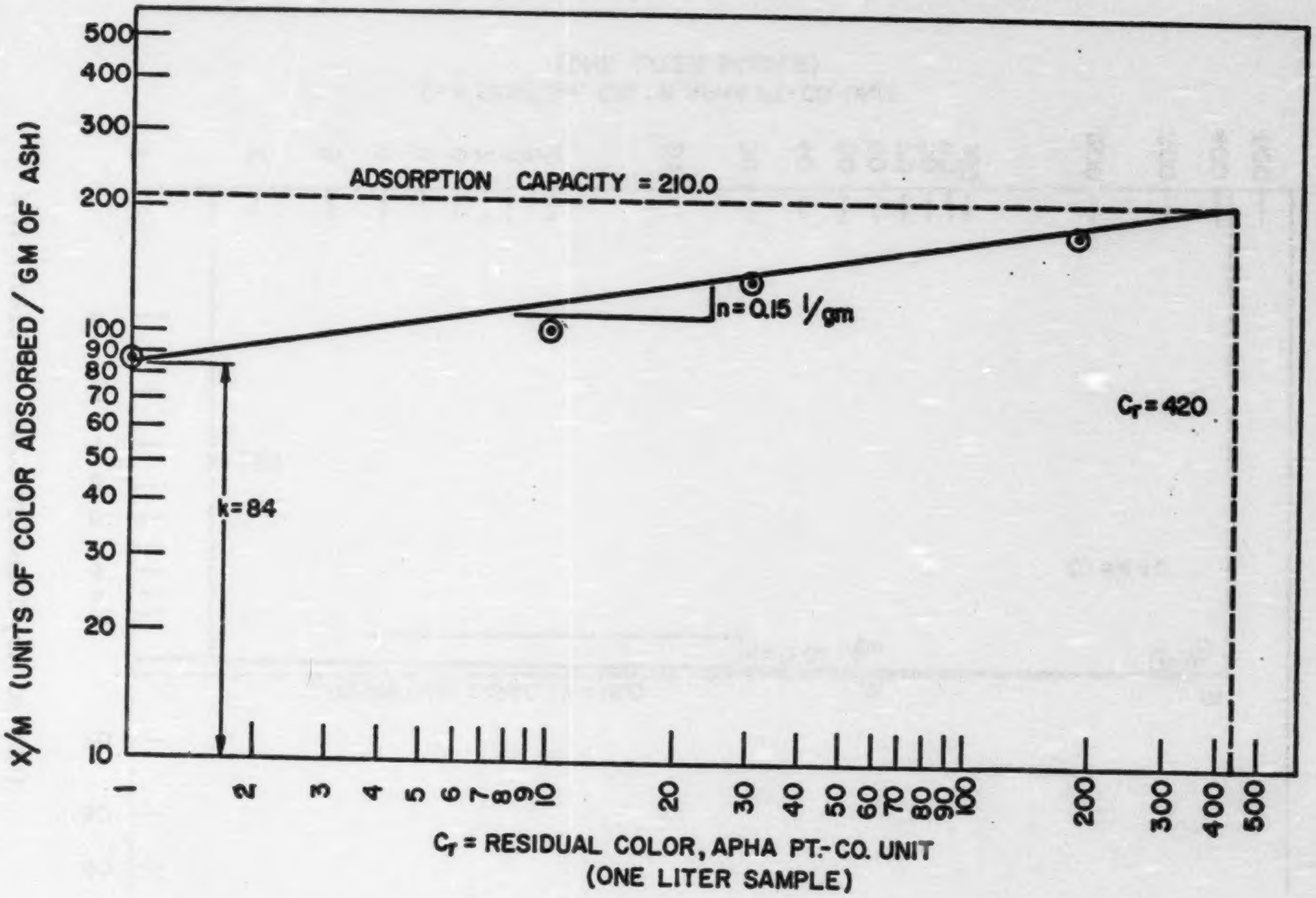

Figure 9. Powdered activated carbon isotherm with prefiltered effluent.

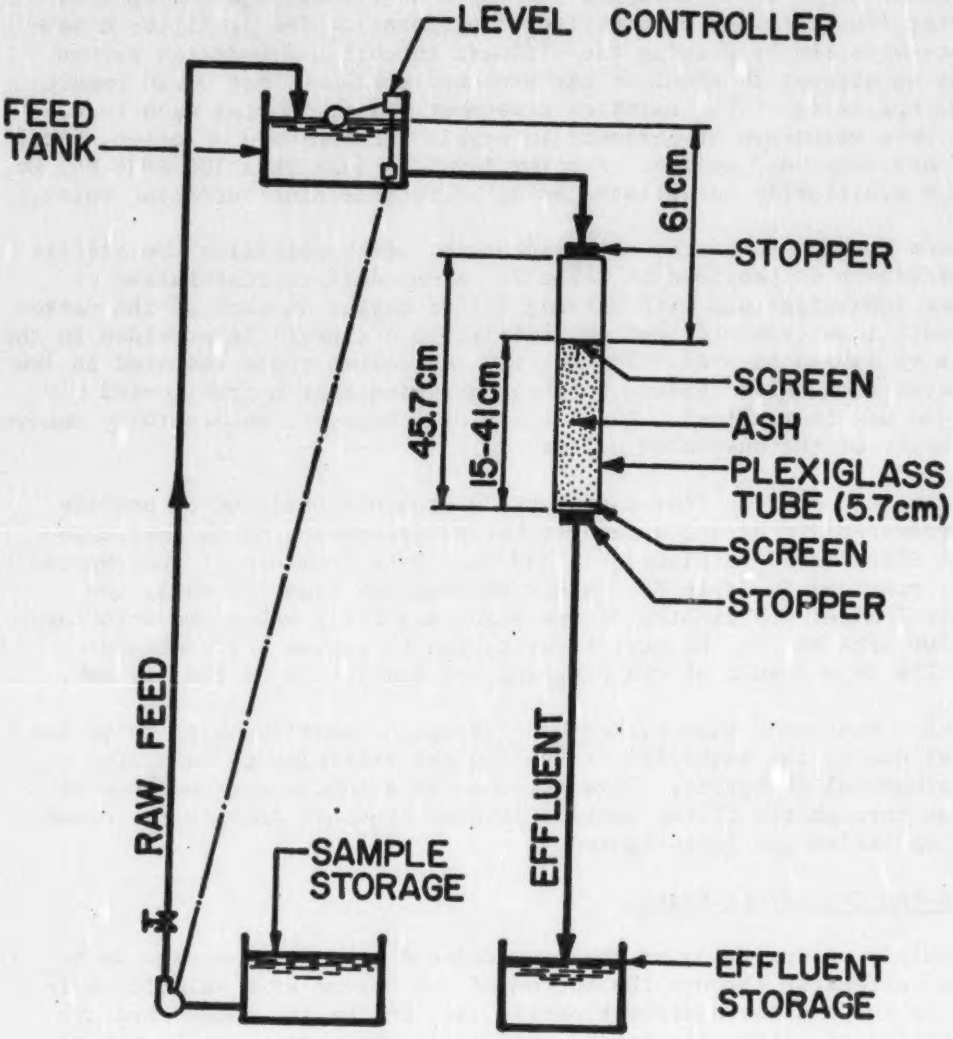
LEVEL CONTROLLER
FEED TANK
61cm
STOPPER
45.7cm
15-41cm
SCREEN
ASH
PLEXIGLASS TUBE (5.7cm)
SCREEN
STOPPER
RAW FEED
EFFLUENT
SAMPLE STORAGE
EFFLUENT STORAGE

Figure 10. Gravity feed, packed bed contacting test apparatus.

The objectives of the first series of investigations utilizing the gravity feed column were as follows:

1. Determine the adsorption characteristics of the packed-bed fly ash column.

2. Evaluate the feasibility of utilizing the fly ash column for the dual purpose of color adsorption and suspended solids removal.

Variables of these tests included the depth of fly ash and the type of wastewater (raw effluent or prefiltered effluent). The prefiltered samples were obtained by passing the effluent through a 710 micron screen. This was an attempt to simulate the expected effluent that would result from the upgrading of the existing treatment plant. During each test, samples were withdrawn at periodic intervals for analysis of color, total solids, and suspended solids. A color level of less than 100 APHA Pt. Co. units was arbitrarily established as an acceptable final effluent color.

Data taken during one of the more successful tests utilizing the prefiltered effluent is provided in Table 7. Also, data representative of the other investigations with varying filter depths on each of the wastewater conditions (raw effluent or prefiltered effluent) is provided in the Appendix as Tables A3 - A4. The gravity fed column tests resulted in low and erratic flow rates leading to the conclusion that a gravity-fed fly ash column was impractical. The columns did, however, successfully remove the majority of the suspended solids.

To overcome the erratic flow rates, the system was modified to provide for a pressurized feed and a sand filter pretreatment. This test apparatus is illustrated in Figures 11 and 12. Data from one of the typical tests is provided in Table 8. As may be detected from the data, the color level after 430 minutes of operation was still below the colorless level (100 APHA Pt. Co. Units); however, the flow rate had declined drastically as a result of the plugging and compaction of the fly ash.

It was thus concluded that packed-bed fly ash columns appeared to be impractical due to the inability of the fly ash particles to maintain their structural integrity. This resulted in a continuous increase of head loss through the filter media. To overcome this difficulty, expanded bed operation was investigated.

Expanded-Bed Contacting System

The principle of operation of the expanded-bed contacting system is to feed the wastewater through the bottom of the column at a velocity sufficient to suspend the adsorbent particles. Unlike the packed-bed system, particulate matter (suspended solids) in the wastewater is not retained in the column. Thus, due to the expanded nature of the bed, head losses do not increase as a function of time.

Table 7. TYPICAL RESULTS OF FLY ASH PACKED-COLUMN TESTS WITH PREFILTERED EFFLUENT[a]

Test Conditions:

Fly Ash Bed Depth	25.4 cm (10 inches)
Fly Ash Weight	318 gm (0.70 lbs.)
Wastewater	Filtered Effluent (710 micron screen)
Mode of Contact	Gravity, Downflow

Elapsed Time (min.)	Flow Rate $l/min/m^2$	Color (APHA Pt. Co. Units)	Total Solids (mg/l)	Susp. Solids (mg/l)
Effluent		2150	1232	74
Filtered Effluent	-	1895	977	50
0	33.16	30	3974	6
30	21.88	20	1377	11
60	13.65	35	1173	9
90	13.65	50	1197	9
120	13.65	50	1240	6
150	12.91	60	1225	7
180	9.78	110	1406	9
210	7.82	310	1203	7

Total volume of effluent with color 100 APHA Pt. Co. Units = 7.6 liters

[a] Samples were prefiltered with U. S. Standard Seive No. 325.

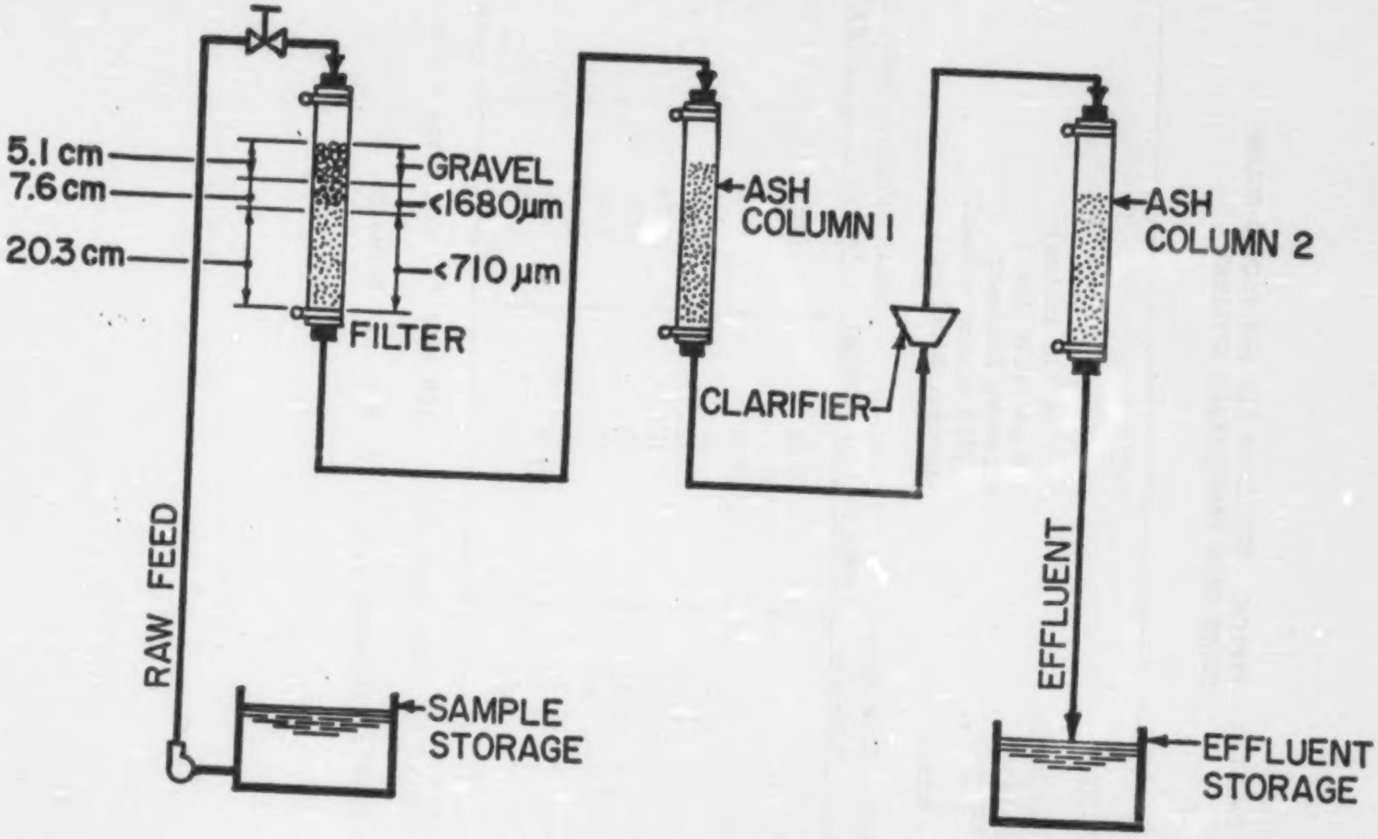
5.1 cm
7.6 cm
20.3 cm
GRAVEL
<1680μm
<710 μm
FILTER
ASH COLUMN 1
CLARIFIER
ASH COLUMN 2
RAW FEED
SAMPLE STORAGE
EFFLUENT
EFFLUENT STORAGE

Figure 11. Pressurized packed bed contacting test apparatus.

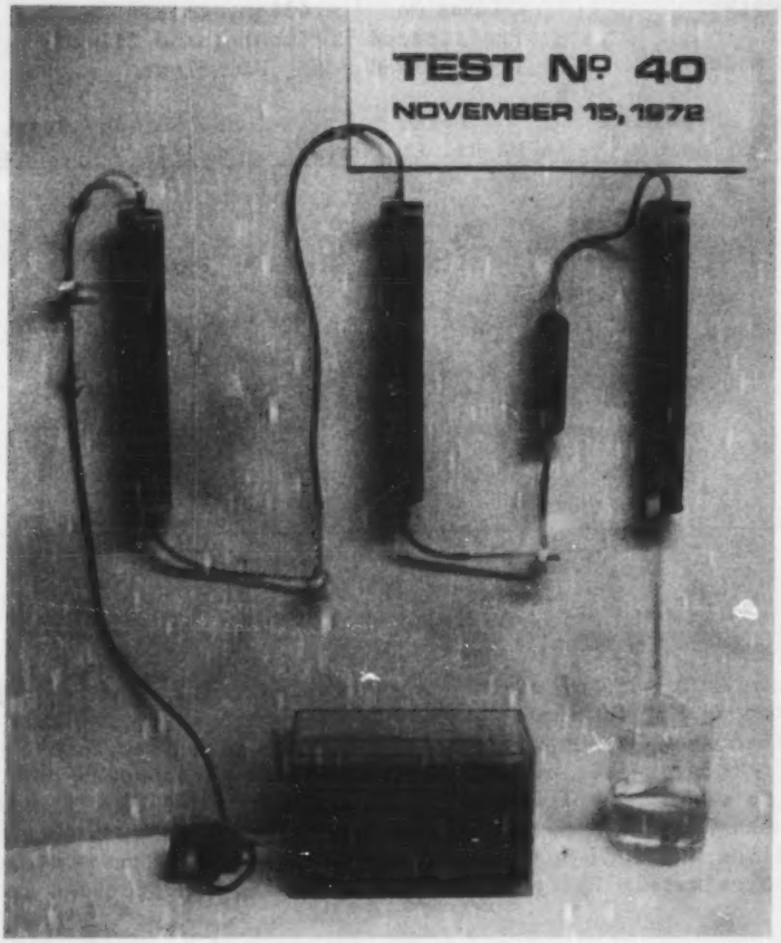
TEST Nº 40
NOVEMBER 15, 1972

Figure 12. Pressurized packed-bed fly ash test apparatus.

Table 8. TYPICAL PACKED-BED FLY ASH TEST RESULTS

Test Condition:

Fly Ash Bed Depth	Column No. 1 - 25.4cm, Column No. 2 - 25.4cm
Fly Ash Weight	Column No. 1 - 454gm, Column No. 2 - 453gm
Wastewater	Prefiltered Effluent (sand filter)
Operation Mode	Pressurized Feed, Downflow

Elapsed Time (min.)	Flow Rate ($l/min/m^2$)	Color (APHA Pt. Co. Units)	Total Solids (mg/l)	Susp. Solids (mg/l)
Effluent	-	1300	3706	122
Filtered Effluent	-	1150	2952	15
0	81.89	0	4291	13
23	70.07	0	2710	15
53	63.96	0	2898	14
90	54.59	0	1145	12
160	58.67	0	4590	19
263	52.55	0	-	13
430	32.59	30	2960	22

To investigate this mode of wastewater - fly ash contact, a test apparatus as illustrated in Figure 13 was utilized. The principle problem encountered with this test set-up was that the fly ash tended to form conglomerated masses. These masses of fly ash then formed into packed beds at various points within the fly ash column depending upon flow rate and resulted in channeling of flow. This phenomenon, therefore, negated the advantage of the expanded-bed mode of operation. Data from a typical test with approximately fifty percent bed expansion is provided in Table 9.

Due to the difficulties encountered with the cohering properties of the fly ash in the columns and the resulting hydraulic conditions, it was concluded that further studies utilizing the column mode of contact were impractical. At this time, the investigation was directed toward the use of a slurry contacting system.

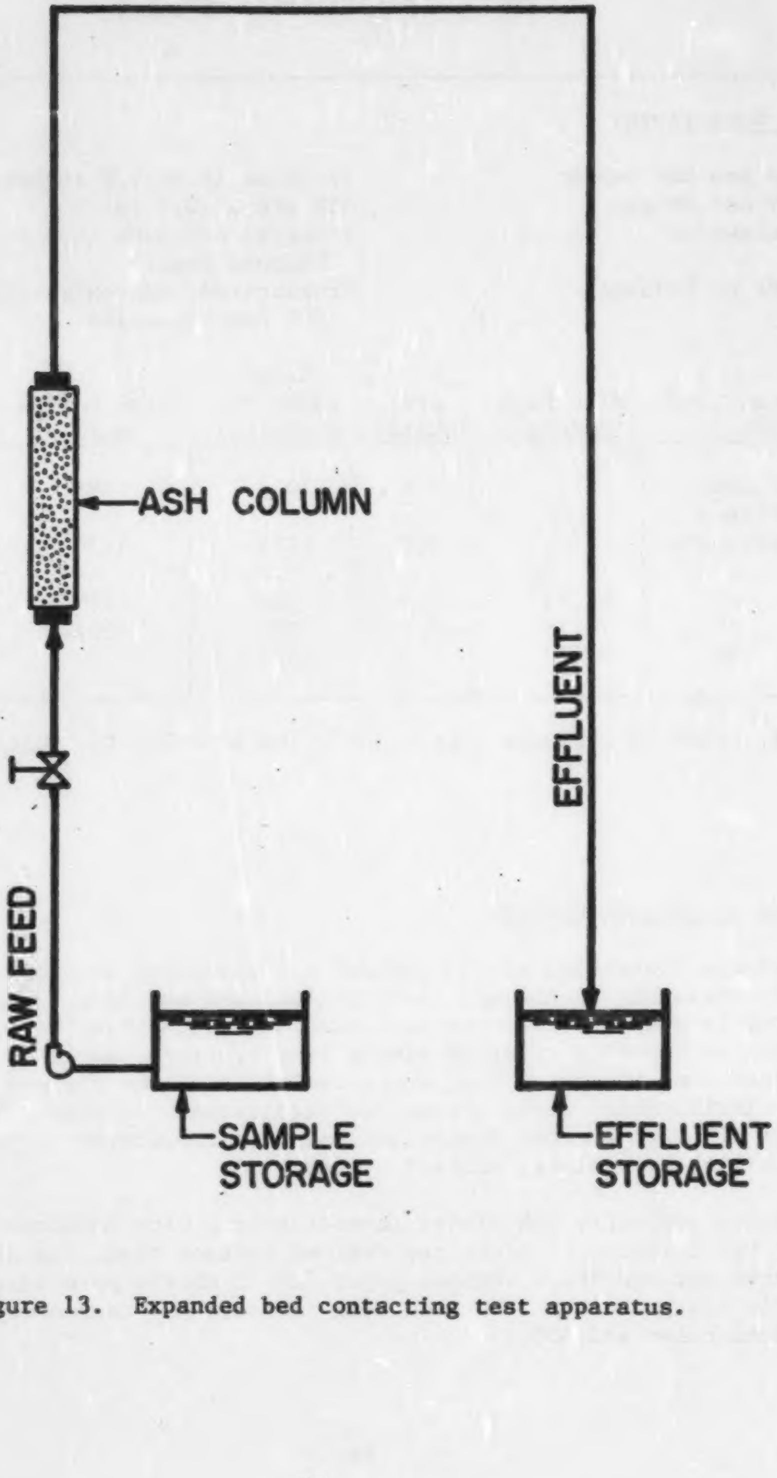
ASH COLUMN
EFFLUENT
RAW FEED
SAMPLE STORAGE
EFFLUENT STORAGE

Figure 13. Expanded bed contacting test apparatus.

Table 9. RESULTS OF FLY ASH EXPANDED-BED TEST WITH PREFILTERED EFFLUENT

Test Conditions:

Fly Ash Bed Depth	22-28 cm (8.7-11.0 inches)
Fly Ash Weight	318 grams (0.7 lbs.)
Wastewater	Filtered Effluent (No. 4 Whatman Paper)
Mode of Contact	Pressurized, Approximately 50% Bed Expansion

Elapsed Time (min.)	Flow Rate (l/min/m^2)	pH (Units)	Color (APHA Pt. Co.Units)	Total Solids (mg/l)	Susp. Solids (mg/l)
Effluent	-	9.8	2025	1745	84
Filtered Effluent	-	9.8	1720	1430	62
5	81.89	7.4	50	2175	-
15	74.15	9.1	125	1557	-
45	58.67	9.3	675	-	-

Total volume of effluent with color $<$ 100 APHA Pt. Co. Units = 2.84 liters

Slurry Contacting System

The slurry contacting system employs a combination of simple unit operations consisting of mixing, flocculation, and settling. The results of the thirty minute adsorption isotherms indicated that the fly ash was capable of removing color in slurry type systems. Also, preliminary data obtained concerning settling characteristics of the fly ash indicated that clarification would present no significant problems. Therefore, a series of batch reactor investigations were undertaken to determine the feasibility of a slurry contact system.

The bench scale fly ash slurry investigations were conducted with a 30-liter batch reactor. After the desired contact time, the slurry was filtered through No. 4 Whatman paper (20-25 micron pore size) to remove the fly ash granules. The resulting filtrate was then analyzed for residual color and BOD$_5$.

The results of these tests are shown in Tables 10 & 11. These tests demonstrate very conclusively that the quantity of fly ash available per volume of wastewater is insufficient to accomplish a significant color reduction. The results also show that the adsorption reaction is essentially complete after the initial 30 minute contact time.

Further studies were conducted to ascertain the effect of pH and temperature on the adsorption properties of the fly ash. These tests, as tabulated in Tables 12 & 13, show that the color adsorption is slightly greater with increasing temperatures and acidic pH levels. The increased adsorption capacity of the fly ash at acidic pH ranges corresponds to the theory that the increased ionization or increased hydrogen-ion concentration results in the neutralization of the negative surface charges found on the surface of carbon. Thereby, the hindrance to diffusion is reduced and more active surface of the carbon is available for adsorption[8]. Further discussion of the interactions of acids and bases with activated carbons is available in the literature[9,10,11]. The increased color removal accomplished with increasing temperature is believed to be a result of an increase in the rate of adsorption rather than in the adsorption capacity. While the rate of adsorption is directly related to the activation energy and therefore a function of temperature, the extent of adsorption is, however, indirectly related to temperature, thus increases with decreasing temperature[8]. The range of temperatures investigated within this study was concluded to be too small to alter the extent of adsorption to a significant degree, therefore, the increased adsorption was attributed to the increased rate of adsorption.

For comparative purposes, a similar series of investigations was also performed utilizing Westvaco's Aqua Nuchar A - powdered activated carbon. During these tests, the powdered activated carbon was added in amounts equal to the fly ash additions in the earlier investigations (23, 47, and 71 grams). This amount is equivalent to one, two and three times the amount of fly ash produced on site per 30 liters of final effluent wastewater discharged. Because this investigation was for comparative purposes, the test period was limited to thirty minute batches only. The resulting data from these powdered activated carbon investigations is provided in Table 14. The results of the powdered activated carbon slurry tests show the superiority of the activated carbon to fly ash. Further study involving activated carbon was beyond the scope of this study.

Table 10. FLY ASH SLURRY CONTACT TEST
RESULTS WITH UNFILTERED EFFLUENT

A. Wastewater — 30 liters (Final Effluent)
Fly Ash Addition — 23 grams (Equivalent to 75 lbs/hr at a flow rate of 190 gpm)

Contact Time (Minutes)	Color (APHA Pt. Co. Units)	BOD_5 (mg/l)
Raw wastewater	3400	1099
30	2800	208
60	2900	130
90	2800	199

B. Wastewater — 30 liters (Final Effluent)
Fly Ash Addition — 47 grams (Equivalent to 150 lbs/hr at a flow rate of 190 gpm)

Contact Time (Minutes)	Color (APHA Pt. Co. Units)	BOD_5 (mg/l)
Raw wastewater	2900	182
30	950	29
60	950	16
90	1000	12

C. Wastewater — 30 liters (Final Effluent)
Fly Ash Addition — 71 grams (Equivalent to 225 lbs/hr at a flow rate of 190 gpm)

Contact Time (Minutes)	Color (APHA Pt. Co. Units)	BOD_5 (mg/l)
Raw wastewater	1900	95
30	1800	59
60	1600	43
90	700	40

Table 11. FLY ASH SLURRY CONTACT TEST RESULTS WITH PREFILTERED EFFLUENT

A. Wastewater — 30 liters (Final Effluent Prefiltered with No. 4 Whatman Paper)

Fly Ash Addition — 23 grams (Equivalent to 75 lbs/hr @ a Flow Rate of 190 gpm)

Contact Time (Minutes)	Color (APHA Pt. Co. Units)	BOD_5 (ppm)
(Prefiltered Wastewater)	1575	75
30	1225	52
60	1200	42
90	1295	70

B. Wastewater — 30 liters (Final Effluent Prefiltered with No. 4 Whatman Paper)

Fly Ash Addition — 47 grams (Equivalent to 150 lbs/hr @ a Flow Rate of 190 gpm)

Contact Time (Minutes)	Color (APHA Pt. Co. Units)	BOD_5 (ppm)
(Prefiltered Wastewater)	1710	85
30	1300	71
60	1310	65
90	1250	54

C. Wastewater — 30 liters (Final Effluent Prefiltered with No. 4 Whatman Paper)

Fly Ash Addition — 71 grams (Equivalent to 225 lbs/hr @ a Flow Rate of 190 gpm)

Contact Time (Minutes)	Color (APHA Pt. Co. Units)	BOD_5 (ppm)
(Prefiltered Wastewater)	1470	73
30	990	51
60	1100	49
90	900	65

Table 12. EFFECT OF pH ON ADSORPTION CAPACITY OF FLY ASH

Test Data:

Slurry Contact Reactor
Fly Ash: 23 grams per 30 liters of wastewater (equivalent to 75 lbs/hr of Fly Ash and 190 gpm)
Contact Time: 30 minutes
Wastewater Profile:

Final Effluent

Color	2950 APHA Pt. Co. Units
COD	283 mg/l
BOD_5	136 mg/l
Suspended Solids	84
Temperature	13° C
pH	8.8

pH Adjustment Chemicals: Sulphuric Acid & Sodium Hydroxide

	Residual			
pH Units	Color (APHA Pt. Co. Units)	COD (mg/l)	BOD_5 (mg/l)	Susp. Solids (mg/l)
2.7	1500	113	72	160
5.3	1900	140	98	64
7.0	2200	138	63	40
8.9	2600	145	78	48
10.7	2600	168	85	48

Table 13. EFFECT OF TEMPERATURE ON THE ADSORPTION CAPACITY OF FLY ASH

Test Data:

Slurry Reactor Contact
Fly Ash: 23 grams per 30 liters of wastewater (equivalent to 75 lbs/hr of Fly Ash and 190 gpm)
Contact Time: 30 minutes
Wastewater Profile:

Final Effluent	
Color	3900 APHA Pt. Co. Units
COD	566 mg/1
BOD_5	285 mg/1
Suspended Solids	216 mg/1
Temperature	13° C

		Residual		
Temperature (C°)	Color (APHA Pt. Co. Units)	COD (mg/1)	BOD_5 (mg/1)	Susp. Solids (mg/1)
5	3000	172	90	76
11	2975	249	189	76
18	2950	174	98	64
25	2900	528	340	60
31	2800	197	106	64

Table 14. POWDERED ACTIVATED CARBON SLURRY CONTACT TEST RESULTS

A. Wastewater 30 liters (Final Effluent)

Powdered Activated Carbon (grams)	Color (APHA Pt. Co. Units)	BOD_5 (mg/l)
(Raw Wastewater)	220	53
23	1200	50
47	875	55
71	310	27

B. Wastewater 30 liters (Final Effluent Prefiltered with a 325 mesh screen)

Powdered Activated Carbon (grams)	Color (APHA Pt. Co. Units)	BOD_5 (mg/l)
(Prefiltered Wastewater)	1580	42
23	1145	52
47	930	45
71	175	26

SUMMARY OF CONCLUSIONS OF FLY ASH COLOR ADSORPTION STUDY

The results of the preceding fly ash investigations led to the following conclusions:

1. Fly ash is capable of removing color, BOD_5, and COD from the wastewaters at Canton Textile Mills, Inc. The adsorption capacity of fly ash, however, is significantly below that of powdered activated carbon.

2. Slurry contacting investigations have shown conclusively that the quantity of fly ash produced at Canton Textile Mills, Inc. is much less than that necessary to accomplish the desired color reduction.

3. The adsorption capability of the fly ash can be improved in acidic pH ranges in accordance with the dominate theory that the increased ionization effects the surface properties of the adsorbing material. A similar adsorption capability improvement resulting with increasing temperatures was concluded to be attributable to an increased adsorption rate rather than increased adsorption capacity.

4. Problems related to hydraulic plugging as a result of the fineness of the fly ash particles and suspended solids present in the wastewater, led to the conclusion that consideration of column (packed or expanded-bed) contacting systems was impractical.

SECTION V

CHEMICAL DESTABILIZATION FOR REMOVAL OF COLOR

Until recently, the typical approach utilized for treating textile wastewaters has resulted in a treatment scheme in which the total wastestream was biologically treated by some oxidative process such as the activated sludge or extended aeration processes[12]. Although this treatment approach is moderately successful in reducing the total organic content, it has been relatively unsuccessful in removing color. Typically, textile dyeing and finishing operations are also subject to interrupted schedules and wide variations of process chemicals which in turn cause wide fluctuations in the operational performance of these biological systems. The presence of toxic dyestuffs, particularly sulfur dyes, as well as toxic emulsifiers and leveling agents also tax the operating efficiency of these biological systems[13]. Because of the aforementioned shortcomings of biological systems and the increasing public pressure to eliminate color from wastewater discharges, chemical coagulation techniques are now beginning to gain prominence.

Historically, chemical coagulation techniques have been reported in the literature to be successfully employed in the textile industry in reducing the BOD in strong textile wastes[14], as a polishing process on biologically treated effluent[15], and as a complete treatment process for the removal of toxic materials as well as color from the dyeing and finishing wastestreams[16]. Coagulants which have been reported as effective in treating textile waste effluents include: calcium hydroxide (lime), ferrous sulfate, ferric chloride, calcium chloride, and aluminum sulfate (alum)[13].

CHEMICAL DESTABILIZATION

Chemical clarification or destabilization generally consists of four steps: coagulation, flocculation, sedimentation and filtration. As a wastewater treatment process, coagulation is defined as the addition of chemicals (coagulants) to effect destabilization and aggregation of nonsettleable suspended materials, commonly referred to as dispersions. The materials generally comprising these dispersions typically range in size from 0.1 millimicrons to 100 microns and are commonly termed colloids. The result of the chemical addition is the formation of floc particles which have the ability to adsorb, entrap, or to aggregate the suspended colloidal particles. Most of the flocculated material is then removed by sedimentation with the remainder removed by filtration.

There are several dominant theories associated with the mechanics of colloidal destabilization and the principles governing coagulation. Discussion of those theories and principles is beyond the scope of this report; however, it can be found in the literature[17,18,19,20]. Likewise, a discussion of the chemistry and stoichiometry of chemical coagulation reactions is also well documented in the literature[18,19,20], and has, therefore, been omitted from this discussion.

Preceding page blank

Laboratory investigation of the applicability of various chemical coagulants is typically accomplished by the use of a series of jar tests. This test consists of a series of sample containers (typically six) which may be mixed by individual mechanically-operated stirrers. The samples to be treated are placed in the containers with the coagulants added while the contents are mixed. After a period of rapid agitation to ensure complete dispersion of the coagulant, the mixing rate is reduced and a period of particle aggregation (flocculation) is allowed to continue. After the flocculating period, the mixing is stopped and the floc allowed to settle for a selected time at which the supernatant may be withdrawn for analysis. A typical step-by-step procedure description of the jar test methods utilized during this investigation is provided in the Appendix as Table A5.

The jar test attempts to simulate the full scale coagulation-flocculation process under controlled laboratory conditions. The use of the jar test investigations affords the opportunity for taking a multitude of observations pertaining to optimization of coagulants, effective pH ranges, and characteristics of supernatant liquids or sludges. These studies may also be employed as a basis for treatment plant design, although final design must feature flexibility in mixing and feeding equipment to proide for the differences between batch and continuous flow processes.

LABORATORY INVESTIGATION

The primary objective of the laboratory investigation was to evaluate the applicability and effectiveness of several chemical destabilizing agents for removing color from the various wastestreams of Canton Textile Mills, Inc. The investigation was carried out in two phases. The objective of the first phase was to determine the point within the wastewater system at which chemical destabilization would be most effective. The objectives of the second phase of the investigation was then, to select the destabilizing agent best suited for application on the wastestream selected. This selection was to be based upon supernatant quality, chemical dosage requirements, as well as the various parameters associated with sludge handling and disposal (i.e., sludge volume, sludge filterability, and chemical recycle feasibility).

Destabilization Investigations

In the first phase of the chemical destabilization investigations, four wastewater streams were selected as potential points for chemical addition. These four points were:

1. Wastewater stream from the indigo dyeing process.
2. Wastewater stream from the sulfur dyeing process.
3. Combined wastewater stream from the two dyeing processes.
4. Effluent from the existing (prior to upgrading) biological wastewater treatment plant.

Because attention at this stage of the investigation was centered primarily upon color removal, the selection of the optimum location was based entirely upon the color quality of the supernatant, relative chemical dosage requirements, and visual observations related to the various sludges. Eight destabilizing agents or combinations thereof were utilized in the initial screening series of jar tests. A series of jar tests wasconducted with each of eleven destabilizing agent combinations on each of the four wastewater streams to determine the optimum color removal. Various pH ranges were also investigated for each destabilizing agent to insure optimum chemical dosage. The results of these preliminary screening investigations are provided in Table 15.

These preliminary investigations indicated that chemical destabilization of the wastestreams from the dyeing processes, either separate or combined, would be difficult. In most cases, regardless of chemical dosage, the color concentration of these wastestreams could not be brought below 100 APHA Pt. Co. Units. In those few cases where the level of 100 APHA Pt. Co. Units could be reached, the chemical dosages required were economically impractical.

Chemical destabilization investigations performed on the effluent from the existing biological system, however, demonstrated that seven of the destabilizing agents could successfully reduce the color levels to or below 100 APHA Pt. Co. Units. Of these seven, three — concentrated sulfuric acid, calcium chloride, and ferric chloride — produced sludges that were impractical to dewater due to their extreme fineness and excessive volume. Aluminum sulfate, magnesium carbonate hydrolyzed with lime, lime, and lime with an anionic polyelectrolyte visually demonstrated the ability to produce a supernatant with low color concentrations while producing a sludge with good settling properties.

At this point of the investigation, an additional series of jar tests was performed on the effluent from the biological treatment system with each of the four successful coagulants. These tests were designed to evaluate the effect of daily fluctuations of the wastewater over a week period and to establish optimum coagulant dosages. During these tests, the quality of the supernatant was analyzed in terms of BOD_5, COD, and suspended solids. The results of these tests as summarized in Table 16 reinforced the earlier conclusions regarding the ability of these coagulants to satisfactorily remove color. They also demonstrated the ability of the coagulants to produce a supernatant with low BOD_5, COD, and suspended solids concentrations.

Sludge Characterization

To further evaluate the respective coagulants, the investigations included characterizing the various sludges. Sludge in sufficient quantities for analysis was obtained through the use of a thirty-liter batch reactor. Each of the coagulant sludges were produced by reacting

Table 15. SUMMARY OF PHASE ONE JAR TEST INVESTIGATIONS

Destabilizing Agent	Indigo Dyeing Wastewater		Sulfur Dyeing Wastewater		Combined Dyeing Wastewater		Biol. Treatment Plant Effluent	
	Dosage[a]	Color[b]	Dosage[a]	Color[b]	Dosage[a]	Color[b]	Dosage[a]	Color[b]
Initial	-	6500	-	30,100	-	16,000	-	1400
H_2SO_4(Conc.)	1.0 ml (pH=2.0)	3500	10.0 ml (pH=0.5)	100	6.0 (pH=1.0)	550	40 (pH=1.0)	80
$Al_2(SO_4)_3 \cdot 18H_2O$	33,000(Al^{+3}) (pH adj.to 5.5)	750	30,000(Al^{+3}) (pH adj.to 5.5)	60	600(Al^{+3}) (pH adj.to 5.5)	380	20(Al^{+3}) (pH adj.to 5.5)	30
$Al_2(SO_4)_3 \cdot 18H_2O$ & $Ca(OH)_2$	25,000(Al^{+3}) 5300	550	30,000(Al^{+3}) 10,000	360	40(Al^{+3}) 5000	400	NO TEST	
$Ca(OH)_2$	5300		25,000	500	4500	250	1500	90
$Ca(OH)_2$ & $MgCO_3 \cdot 3H_2O$	NO TEST		10,000 40	620	10,000 15	390	1500 15	60
$Ca(OH)_2$ & Dow A-23	NO TEST		10,000 4	570	4000 4	425	1500 4	100
$Ca(OH)_2$ & $FeSO_4 \cdot 7H_2O$	2500 7000	60	5000 10,000	250	2600 5000	150	NO TEST	
$Ca(OH)_2$ & $FeCl_3 \cdot 6H_2O$	NO TEST		5000 10,000	80	3300 4000	80	NO TEST	
$CaCl_2$	5000	780	5000	30,100	4000	600	5000	100
$FeCl_3 \cdot 6H_2O$	4000	850	5000	2000	380	16,000	250	25
$FeSO_4 \cdot 7H_2O$	30,000	300	3500	1400	2000	150	1000	280

[a] Dosage as mg/l and as destabilizing agent form denoted unless otherwise indicated.

[b] Color as APHA Pt. Co. Units

Table 16. AVERAGE RESULTS OF SUCCESSFUL JAR TESTS ON EXISTING WASTEWATER TREATMENT PLANT EFFLUENT[a]

	Supernatant Resulting From Coagulation With:				
Parameter	Waste-Water	$Al_2SO_4 \cdot 18H_2O$	$MgCO_3 \cdot 3H_2O$ & $Ca(OH)_2$	$Ca(OH)_2$	$Ca(OH)_2$ & Anionic Polyelectrolyte
Coagulant Dosage[b] (mg/l)	-	20(Al^{+3})	15 & 1500	2000	1500 & 4
pH (Units)	6.8	5.5	12.6	12.5	12.8
Color (APHA Pt. Co.Units)	1216	30	60	65	30
BOD_5 (mg/l)	57	14	11	15	13
COD (mg/l)	165	39	33	37	19
Suspended Solids (mg/l)	123	3	33	30	19

[a] Values within Table respresent the average of five-days of testing designed to evaluate the various coagulants' effect on the wastestream's normal daily deviation resulting from production variations.

[b] Coagulant dosage is in form denoted unless otherwise indicated.

thirty liters of wastewater with the previously established optimum coagulant dosages. Upon completion of the coagulation, flocculation, and sedimentation cycles, the supernatant was carefully decanted. The remaining sludge was poured into a two-liter graduate and allowed to settle for sixty minutes. At this time, the sludge volume was noted, the supernatant again decanted, and the remaining sludge analyzed for density and moisture content. A minimum of three such tests were performed for each coagulant. The average of the test results are tabulated in Table 17.

Alum Sludge Investigations

In reviewing the relative sludge characteristics, the primary disadvantages associated with alum coagulation were the excessive sludge volume and high moisture content. In an effort to produce a more favorable alum sludge, a series of jar tests was performed to investigate the benefits of several selected polyelectrolytes and coagulant aids. The results of these investigations which are tabulated in Table 18 show an insignificant improvement in sludge volume derived from the coagulant aids investigated. It is recognized, however, that the investigation of polyelectrolytes was somewhat limited. Although polyelectrolytes representative of the three basic types (i.e., cationic, nonionic, and anionic)were investigated, it must be acknowledged that there are endless varieties of polyelectrolytes available from the various manufacturers which might prove much more beneficial in improving the sludge characteristics.

Table 17. SLUDGE CHARACTERIZATION

Coagulant	Sludge Volume after 60 min. (% of total)	Sludge Density (gm/cm^3)	Moisture (%)	Estimated Full Scale Sludge Volume (m^3/hr)	Estimated Full Scale Dry Sludge (kg/hr)
$Al_2(SO_4)_3\cdot 18H_2O$	5.4	1.001	99.5	1.85	9.26
$MgCO_3\cdot 3H_2O$ & $Ca(OH)_2$	2.1	1.003	97.3	0.72	19.50
$Ca(OH)_2$	1.7	1.027	97.0	0.56	17.25
$Ca(OH)_2$ & DOW A-23	1.6	1.012	95.4	0.56	26.07

Table 18. SUMMARY OF ALUM SLUDGE REDUCTION INVESTIGATIONS[a]

Coagulant Aid	Dosage (mg/l)	Sludge Volume (%Tot.)	Supernatent		
			Susp. Solids (mg/l)	COD (mg/l)	Color (APHA Pt. Co. Units)
	-	5.4	16	62	30
Activated Silica	25	4.0	2	80	30
Bentonite	25	5.0	8	62	20
Dow A-23 (Anionic Polyelectrolyte)	4	5.0	28	23	30
Dow N-20 (Nonionic Polyelectrolyte)	5	b	80	47	20
Dow C-41 (Cationic Polyelectrolyte)	40	5.0	28	54	20
Fly Ash (From C.T.M. Inc.'s Boiler)	930[c]	4.0	40	18	80

[a] Alum Dosage: 20mg/l as Al^{+3}

[b] Resulted in partial sludge flotation.

[c] Dosage is equivalent toquantity of fly ash available from mills boiler, per volume of wastewater.

Further work in this area was beyond the scope of this phase of the project; however, additional investigation is recommended prior to pilot scale testing.

Coagulant Regeneration

The feasibility of coagulant regeneration and reuse was investigated in a series of bench scale tests. The procedures and the resulting conclusions are summarized below:

Aluminum Sulfate (Alum) - Recovery of alum from waste sludge is simply a reversal of the precipitation process. After preliminary thickening and/or dewatering, the sludge, consisting mostly of aluminum hydroxide, is treated with sulfuric acid. The alum is regenerated according to the following reaction:

$$2Al(OH)_3 + 3H_2SO_4 \longrightarrow Al_2(SO_4)_3 + 6H_2O \qquad (03)$$

Stoichiometrically, by calculating the weights of each of the two compounds, it may be determined that approximately 1.9 lbs. of sulfuric acid is required to regenerate each pound of aluminum hydroxide. Previous studies conducted on alum recovery[24], have reported that adjustment of the pH to a range between 1.5 - 2.5 is necessary to insure complete conversion of the aluminum hydroxide to aluminum sulfate.

The alum recovery investigations were performed on the sludge recovered from 30 liter batch coagulation tests. This sludge was collected in a two-liter graduate and acidified according to 1.9 parts concentrated sulfuric acid per each part $Al(OH)_3$ (calculated from the quantity of Al^{+3} present in the sludge) or to a minimum pH level of 1.5. After approximately 15 minutes of agitation, the mixture was allowed to settle and the resulting supernatant decanted and analyzed for aluminum. This supernatant was then utilized for subsequent coagulation tests. The results of the alum regeneration investigations lead to the following discussion and conclusions:

1. Acidification of the sludges produced by alum coagulation did release alum in sufficient quantities for reuse. The results from one of the more successful series of alum coagulation-regeneration investigations are provided in Table 19. These results demonstrate the progressive loss of alum with each regeneration. A mass balance of the aluminum ion (Al^{+3}) present at the various stages of the regeneration process indicated that varying amounts of the aluminum were irreversibly tied up in the sludge. A range from 15 to 60 percent of the initial aluminum addition was lost with each coagulation. It is felt that the percentage of aluminum loss to the sludge is largely a function of raw wastewater quality (i.e., pH, hardness, color, etc.). The degree of alum recovery for reuse in these investi-

Table 19. TYPICAL RESULTS OF ALUM REGENERATION—COAGULATION INVESTIGATIONS

Coagulant Dosage (mg/1 as Al^{+3})	Total Coagulant Addition (mg/as Al^{+3})	Total Coagulant in Regenerated Sludge Supernatant (mg as Al^{+3})	% Alum Recovery[b]	Initial Wastewater		Coagulant Supernatant		
				COD (mg/1)	Color (APHA Pt.Co.Units)	pH (units)	COD (mg/1)	Color (APHA Pt.Co.Units)
20	600	297	49	143	1650	5.5	32	30
20[a] (1st Regen.)	198	136	22	132	2000	5.5	39	40
20[a] (2nd Regen.)	102	87	14	120	1600	5.5	58	20

[a] The volume of wastewater used for each successive coagulation test was reduced to permit constant Al^{+3} dosage.

[b] Based on quantity of Al^{+3}) added initially (600 mg).

gations was also partially influenced by the failure to completely dewater the final sludges after regeneration. This loss was overcome by reducing the volume of each successive coagulation test in order to maintain a constant coagulant dosage.

2. Although the regenerated alum demonstrated the ability to remove color at efficiencies comparable to that of the fresh alum, the settling properties of the sludge produced with each successive coagulation test progressively deteriorated.

3. The final sludge remaining after recovery of the alum was visually observed to be much more gelatinous than the original alum sludge. This might present problems in final dewatering steps. Other potential problem areas include the buildup of impurities in the recovered alum solution and operational problems associated with acidification.

4. In reviewing the relative economics of the chemical costs alone as tabulated in Table 20, it appears that alum regeneration offers a very insignificant economic advantage. It is recognized that there are numerous other economic factors that should be considered in evaluating the potential benefits of alum regeneration. The results of the relative chemical costs, however, indicate that regeneration of alum for this application is at best, marginal. Further pilot scale testing is necessary to more closely define the alum recovery, sludge dewatering requirements, and ultimate disposal considerations.

Table 20. RELATIVE ECONOMICS OF ALUM REGENERATION

	Cost/m^3	Cost/1000 Gal.
Estimated Cost of Alum[a] without Regeneration	$ 1.50	$ 5.67
Estimated Chemical Cost with Regeneration		
Alum[a] Cost @ 50% make-up	0.75	2.83
Sulfuric Acid[b] Required for Regeneration	0.42	1.59
	$ 1.17	$ 4.42
Estimated Chemical Savings with Regeneration	$ 0.33	$ 1.25

[a] Liquid Alum (17% Al_2O_3) @ $68/metric ton

[b] Sulfuric Acid (66°Be, 93% H_2SO_4) @ $36/metric ton

Magnesium Carbonate - Recovery of magnesium carbonate from waste sludge is accomplished by reacting the magnesium hydroxide component of the sludge with carbon dioxide. This solubilizes the magnesium selectively as magnesium bicarbonate which may then be reclaimed from the filtrate in the dewatering process and returned for reuse in the coagulation process[26,27,28]. The basic regeneration chemical reaction is:

$$Mg(OH)_2 + 2CO_2 \longrightarrow Mg(HCO_3)_2 \qquad (04)$$

To investigate the potential application of magnesium carbonate regeneration, a series of recovery tests was performed. These investigations utilized the sludge recovered from a thirty-liter batch, lime-magnesium carbonate coagulation test. The sludge was collected in a graduate cylinder and the volume brought to two-liters with distilled water. During agitation, laboratory grade carbon dioxide was introduced at a low rate until a pH level of 7.5 was reached. At this point, the remaining sludge was allowed to settle for approximately three hours and the supernatant withdrawn for analysis and reuse.

In this investigation, the magnesium source utilized was in the form of magnesium carbonate trihydrate ($MgCO_3 \cdot 3H_2O$). This is a relatively new coagulant and is not available commercially. The basic carbonate - $4MgCO_3Mg(OH)_2 \cdot 5H_2O$ - which is commercially available has a low solubility and is unsatisfactory for practical use as a coagulant[25]. In a full scale system, recovery of the naturally available magnesium from the water would be required for use as a coagulant.

The results of the series of regeneration investigations indicated that approximately 50-70 percent of the magnesium content could be recovered through carbonation of the sludge. The remaining portion of the magnesium was either lost in the supernatant or in the waste sludge. The supernatant quality obtained through coagulation with regenerated magnesium bicarbonate was found to compare very favorably with that obtained utilizing the magnesium concentrations found in the wastewaters (1.5 to 3.0 mg/l as Mg^{++}). It was concluded that magnesium bicarbonate regenerated from the sludges, could produce sufficient quantities to sustain the optimum coagulation requirements. Further evaluation of the potential full scale application led to consideration of the magnesium available as an impurity in commercial hydrated lime. High purity reagent grade lime was utilized in the bench scale investigation. The commercially available hydrated lime utilized by Canton Textile Mills, Inc. for fresh water treatment has a typical magnesium oxide content of 0.73 percent (by weight). Although this content may seem insignificant, at the lime dosages required for this application (1500 mg/l as $Ca(OH)_2$), the magnesium addition from the lime (4.38 mg/l as Mg^{++} per gram of lime) is adequate to meet the magnesium requirements for optimum coagulation. Therefore, it was concluded that magnesium bicarbonate regeneration would not be required for this application.

This magnesium regeneration process, however, might prove beneficial at other locations.

Lime - Recovery of waste lime sludges by recalcination has been practiced successfully for many years by the pulp and paper industry. Recently, the lime recalcination process has also found application in the recovery of wastewater treatment lime sludges[28]. The process of recalcination is accomplished by heating the calcium containing sludges to temperatures ranging between 800 and 1100°C (1500-2000°F)[30]. The basic reaction is as follows:

$$CaCO_3 \xrightarrow{HEAT} CaO + CO_2 \qquad (05)$$

To evaluate the potential use of lime recovery at Canton Textile mills, Inc., a series of batch recalcination tests was performed. The test sludge was recovered from thirty-liter batch coagulation tests and dewatered by oven drying at 103°C (217°F) for a period of 24 hours. The dried sludge was then ground to powder and fired at 930°C (1700°F) for a period of five minutes. Stoichiometrically, if total recovery of the calcium were possible, the addition of one gram of $Ca(OH)_2$ should result in the recovery of 0.76 grams of CaO. Total recovery is not practical and a portion of the final material after firing would be expected to be inert material removed from the wastewater. Based only on a weight recovery comparison, the results of the batch recovery tests indicated that only 38 percent of the theoretically possible recovery could be accomplished. Considering the fact that a portion of the recovered material was inert matter and not CaO, it was concluded that the percentage recovery was actually somewhat less than 38 percent. It was also noted that the supernatant water hardness was increased from an original 50 mg/l as $CaCO_3$ to a final of 1400 mg/l as $CaCO_3$. This indicated that much of the original calcium addition in the lime was lost with the supernatant rather than precipitated.

In considering the economic aspects of lime recalcination, it has been reported at the South Lake Tahoe wastewater plant that the cost of the lime recalcination is slightly greater than the cost of new lime[29]. At this installation which has a design flow of 28,4000 m^3 per day, approximately seventy percent of the required CaO is recovered by recalcination of the lime sludges. In view of these economic aspects, the scale of operation, and the preliminary CaO recovery indications, consideration for recalcination was abandoned.

Sludge Filterability

To investigate the filterability of the various sludges, a series of Buchner funnel tests was performed utilizing the test set-up illustrated in Figure 14. These tests were utilized to provide an indication of filtration times and the effect of various vacuum pressures. Basically, this test consisted of applying a selected vacuum (25, 38, or 51 centimeters of mercury) to the funnel apparatus covered with two No. 4 Whatman filter papers (prewetted to insure a vacuum seal) and containing exactly 200 milliliters of the test sludge. After applying a vacuum for a predetermined period of time, the filtrate was analyzed for volume, color, pH, and COD. The filter cake was also analyzed for percent solids although it was recognized that the comparative moistures of the cakes are unobtainable due to loss of vacuum before normal drying time[30].

A more detailed description of the test procedure is provided in the Appendix as Table A6 and the results of the tests tabulated in Tables A7 through A10 also found in the Appendix.

The results of the Buchner filter tests demonstrated the ability of the lime-Dow A23 coagulation process to produce a sludge lending itself to dewatering by vacuum filtration. This was evident by the ability of this sludge to form a defined filter cake in filtration times of two minutes or less. The other coagulants showed poor cake formation at vacuum periods less than six to eight minutes. This was important because most conventional vacuum filtration equipment is manufactured with drum speeds of 1-10 minutes per revolution with a typical 25-35 percent submergence. Therefore, the filter cake formation period is generally less than 2.5 minutes[31]. In comparing the relative filter cake solids concentrations, the lime-Dow A23 coagulant again demonstrated the ability to produce a filter cake having solids concentrations as high as 11 to 15% at filtration periods of two minutes and without vacuum loss. Aluminum sulfate produced a very poor cake at filtration times less than six minutes with vacuum loss soon after cake formation.

Based upon these conclusions, a series of filter leaf tests was performed with the lime-Dow A23 sludge. The purpose of these tests was to develop design data. The test leaf as illustrated in Figure 15 has the ability to simulate a vacuum filter in operation (i.e., submergence, drying, and removal of the filter cake). Another advantage of the filter leaf is that it is possible to use the same filter media as might be utilized on the full scale vacuum filter. Thus, in short, the results are more representative of the operation of a plant size vacuum filter[32].

The filter leaf were performed in accordance with the following procedure:

1. The filter leaf assembly was submerged in the prepared sludge and the desired vacuum applied for a time period corresponding to the desired form time (1 minute).

2. The leaf was then removed from the sludge and brought to the vertical position for a time corresponding to the desired drying time (3 minutes).

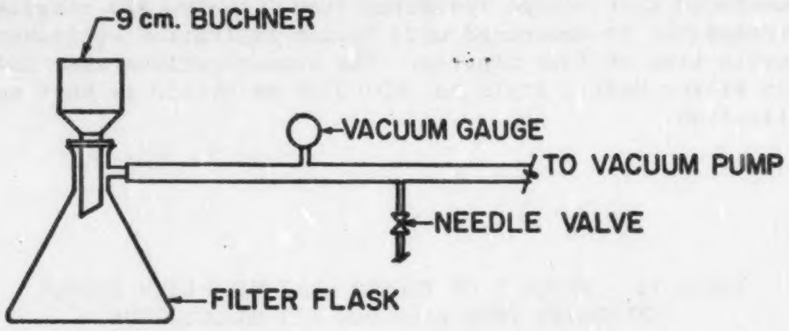
9 cm. BUCHNER
VACUUM GAUGE
TO VACUUM PUMP
NEEDLE VALVE
FILTER FLASK

Figure 14. Buchner funnel test apparatus.

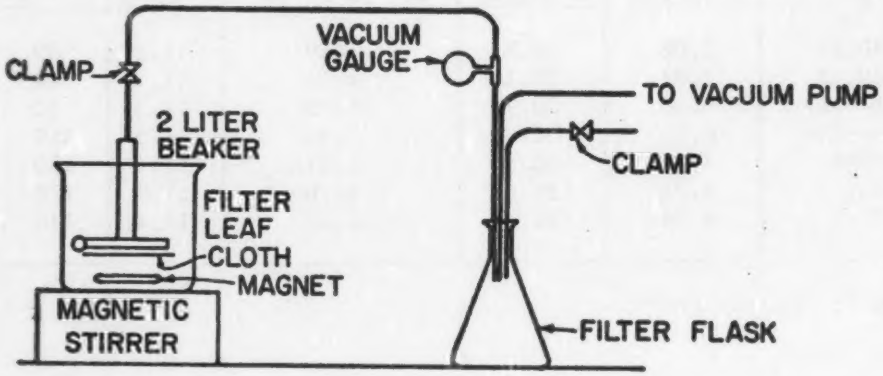
CLAMP
VACUUM GAUGE
TO VACUUM PUMP
2 LITER BEAKER
CLAMP
FILTER LEAF
CLOTH
MAGNET
MAGNETIC STIRRER
FILTER FLASK

Figure 15. Filter leaf apparatus.

3. After drying, the vacuum was released and the filter cake carefully removed for analysis.

Based on the results of these filter leaf tests as tabulated in Table 21, it was concluded that sludge resulting from lime-Dow A23 coagulation could successfully be dewatered with vacuum filtration equipment having a total cycle time of four minutes. The investigations also indicated that Eimco Filter Media, Style No. PO-801RF or NY-333 is best suited for this application.

Table 21. RESULTS OF FILTER LEAF TEST WITH SLUDGE GENERATED FROM LIME-DOW A23 COAGULATION

Basis of Test: Sludge from Lime and Dow A-23 tests

Vacuum, cm Hg = 38.1
Cycle time, min. = 4.0
Form time, min. = 1.0
Dry time, min. = 3.0
Medium - all supplied by EIMCO

				Filtrate		
Medium Style No.	Initial % Solids	Cake % Solids	Filter Yield Dry gm/hr/cm^2	pH, Units	Color, ([a])	COD, mg/1
PO-801RF	5.08	25.4	1.89	11.5	80	127
PO-802HF	7.01	30.1	1.06	11.3	10	93
POPR-854F	7.36	30.9	0.75	11.3	30	108
POPR-925F	6.03	31.7	0.74	11.5	210	100
NY-384F	5.07	30.1	1.11	11.4	180	111
NY-333	4.24	26.6	1.70	11.5	120	203
CO-3	6.34	25.2	1.47	11.4	110	258

[a] APHA Pt. Co. Units

FULL SCALE COST PROJECTIONS

Results of the bench scale coagulation investigations indicated that coagulation of the wastewaters with lime and Dow A-23 polyelectrolyte was the most feasible approach due to the sludge dewatering properties. Based on this treatment concept, preliminary flow diagrams and cost projections were prepared for incorporating the coagulation process into the present wastewater treatment system. The preliminary flow schematic as provided in Figure 16, would require the addition of lime, polyelectrolyte, and sulfuric acid feed and storage systems; a vacuum filtration system; modifications to the existing clarifier and digester; and the related instrumentation and piping changes. Preliminary estimates for this chemical coagulation and sludge dewatering system indicate a capital cost of $330,000 with a total operating cost (including the operation of the existing system) of approximately 23.0¢ per cubic meter of raw wastewater treated. A breakdown of both capital and operating cost is provided in Tables 22 and 23.

In evaluating the chemical costs of the lime coagulation system, it was concluded that the cost of lime and the subsequent sulfuric acid cost required for final neutralization were excessive. Chemical costs alone for the lime coagulation system would be approximately 11.9¢ per cubic meter or $35,000 per year.

In considering the use of alum coagulation, the primary disadvantages encountered were the excessive sludge volume and related problems of dewatering. If a polyelectrolyte or suitable sludge conditioner could be utilized to improve the alum sludge dewatering properties, a substantial savings in chemical costs might be realized with alum coagulation. This would be largely dependent on the costs associated with the sludge conditioning agent. Comparatively, the estimated chemical cost of alum (at a dosage of 20 mg/l as Al^{+3}) is approximately 1.5¢ per cubic meter as opposed to lime (at a dosage of 1500 mg/l as $Ca(OH)_2$) at an estimated cost of 5.8¢ per cubic meter. An additional chemical cost of the alum system, however, would be that of the acid (typically sulfuric) required to adjust the wastewater pH to the optimum coagulation range (5.0-5.5) and the subsequent readjustment of the pH level to a range of 6.0 to 9.0 for final discharge or reuse. The chemical cost associated with the alum system would most likely still be significantly less than that of the lime system which would require final pH adjustment from 12.5 to 9.0 pH units with sulfuric acid at a cost of approximately 5.6¢ per cubic meter. The comparative capital costs of the two systems would be in the same range with an economic trade-off of the lime storage and handling system for the additional expense of alum and caustic storage and feeding systems.

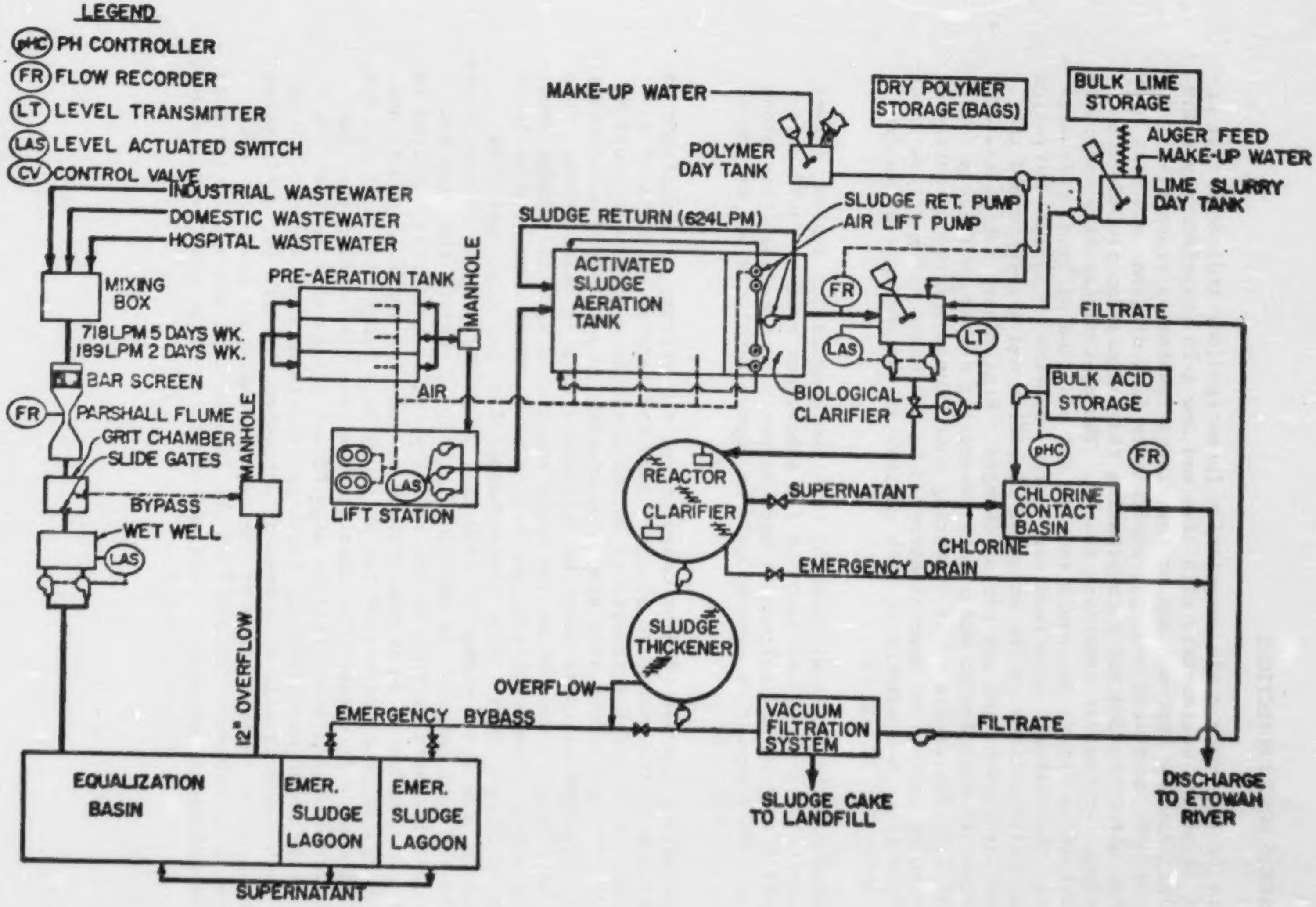
LEGEND
pHC PH CONTROLLER
FR FLOW RECORDER
LT LEVEL TRANSMITTER
LAS LEVEL ACTUATED SWITCH
CV CONTROL VALVE
INDUSTRIAL WASTEWATER
DOMESTIC WASTEWATER
HOSPITAL WASTEWATER
MIXING BOX
718LPM 5 DAYS WK.
189LPM 2 DAYS WK.
BAR SCREEN
FR
PARSHALL FLUME
GRIT CHAMBER
SLIDE GATES
BYPASS
WET WELL
LAS
MANHOLE
12" OVERFLOW
PRE-AERATION TANK
MANHOLE
AIR
LIFT STATION
LAS
MAKE-UP WATER
POLYMER DAY TANK
DRY POLYMER STORAGE (BAGS)
BULK LIME STORAGE
AUGER FEED
MAKE-UP WATER
LIME SLURRY DAY TANK
SLUDGE RETURN (624LPM)
ACTIVATED SLUDGE AERATION TANK
SLUDGE RET. PUMP
AIR LIFT PUMP
FR
LAS
LT
CV
BIOLOGICAL CLARIFIER
FILTRATE
BULK ACID STORAGE
pHC
FR
REACTOR
CLARIFIER
SUPERNATANT
CHLORINE CONTACT BASIN
CHLORINE
EMERGENCY DRAIN
SLUDGE THICKENER
OVERFLOW
EMERGENCY BYBASS
VACUUM FILTRATION SYSTEM
FILTRATE
SLUDGE CAKE TO LANDFILL
DISCHARGE TO ETOWAH RIVER
EQUALIZATION BASIN
EMER. SLUDGE LAGOON
EMER. SLUDGE LAGOON
SUPERNATANT

Figure 16. Flow diagram of treatment system with proposed chemical coagulation addition.

Table 22. ESTIMATED CAPITAL COSTS OF CHEMICAL COAGULATION SYSTEM ADDITION TO CANTON TEXTILE MILLS, INC.'S EXISTING BIOLOGICAL TREATMENT FACILITY[a]

Modifications to Existing Clarifier & Digester (Conversion to Reactor-Clarifier and Thickener)	$ 32,500
Vacuum Filter Station (6' Dia. x 6' Drum with accessory drive, pumps, motors, sludge conveyor, installation, etc.)	85,000
Lime Storage and Feed System (45 ton bulk lime storage, auger feed, day tank, mixer, and slurry metering pump)	42,850
Polymer Feed System (2-day tanks, mixer, and metering pump)	4,500
Bulk Acid (H_2SO_4) Storage and Feed system	6,000
Instrumentation (pH and Flow)	15,000
Sludge Pumps (Clarifier & Thickener)	7,500
Site Preparation	15,000
Housing for Vacuum Filter, Polymer, and Lime Systems	37,500
Piping and Electrical	84,150
TOTAL	$ 330,000

---

[a] *Engineering News Record* Cost Index (1913 Baseline) = 2275.9%

Table 23. PROJECTED OPERATING AND MAINTENANCE COSTS FOR EXISTING BIOLOGICAL AND NEW CHEMICAL COAGULATION SYSTEM[a]

	¢/m^3
Chemical Costs for Coagulation System	
Hydrated Lime @ 38.6 $/metric ton	5.8
Dow A-23 Polyelectrolyte @ 1.10 per kilogram	0.5
Sulfuric Acid (66°Be, 93% H_2SO_4) @ 36 $/metric ton	5.5
Power Costs (@ 2.5¢/Kw-Hr)	
Biological System	3.4
Coagulation System	2.1
Total Operating Personnel and Maintenance Costs	5.5
TOTAL	22.8

[a] Does not include cost for landfill disposal of sludge or value of treated effluent for reuse.

SUMMARY OF CHEMICAL DESTABILIZATION CONCLUSIONS AND RECOMMENDATIONS

The results of the chemical destabilization investigations led to the following conclusions and recommendations:

1. Chemical destabilization of the effluent from the existing biological treatment system was found to be the most advantageous point of coagulant application. This conclusion was based upon the demonstrated ability of the various destabilizing agents in accomplishing removal of color and the production of a high quality supernatant at practical levels of chemical addition.

2. Of the eleven destabilizing agent combinations investigated, it was concluded that alum or lime with an anionic polyelectrolyte would be the two coagulants most feasible for application.

3. Coagulation of the wastewaters with lime (at 1500 mg/l as $Ca(OH)_2$) and an anionic polyelectrolyte (Dow A-23 at 4 mg/l) demonstrated the ability to produce a sludge with superior dewatering characteristics

in comparison to the characteristics of the sludge resulting from alum coagulation. It was also demonstrated that the sludge resulting from lime coagulation was amenable to dewatering with conventional vacuum filtration techniques. Results of filter leaf tests indicated that vacuum filtration might be expected to produce a sludge cake with approximately 25 percent solids and have a filter yield of approximately 1.7 gm/hr/cm or 3.5 lbs/hr/ft^2 (dry basis).

4. Coagulation of the wastewater with alum (at 20 mg/l as Al^{+3}) resulted in the formation of a gelatinous sludge with poor dewatering characteristics. Comparatively, alum coagulation resulted in a sludge volume of 5.4 percent (99.5% moisture) as opposed to a sludge volume of 1.6 percent (95.4% moisture) resulting from coagulation with lime and polyelectrolyte. The results of Buchner filtration tests indicated that the alum sludge was not amenable to conventional vacuum filtration techniques. Several representative polyelectrolyte (anionic, nonionic, and cationic) as well as several common coagulant aids (bentonite, activated silica, and fly ash) were investigated for use in conjunction with alum coagulation for improving the sludge dewatering characteristics. These investigations proved relatively unsuccessful.

5. The potential of coagulant (lime and alum) regeneration and recycle was investigated. In each case, it was concluded that the percentage of coagulant recovery was insufficient to economically justify recovery.

6. In examining the economic aspects of the application of a full scale lime-anionic polyelectrolyte coagulation system, it was projected that the capital costs for incorporating the chemical coagulation and vacuum filtration processes into the existing biological system would require an expenditure of approximately $330,000. The total operating cost including chemicals, power, maintenance, and operating personnel was estimated to be approximately 22.8¢/m^3 (87¢/1000 gal.) of raw wastewater treated. Of the total operating cost, the chemical cost alone was 11.9¢/m^3 (45¢/1000 gal.), leading to the conclusion that lime-polyelectrolyte coagulation was economically impractical for present application.

7. Economically, the use of alum coagulation has the potential of resulting in significant savings in chemical cost in comparison to the chemical cost of lime-polyelectrolyte coagulation. Alum coagulation offers economic advantages over the lime-polyelectrolyte coagulation system in both the cost of optimum coagulant dosage (1.5¢/m^3 for alum coagulation as compared to 6.3¢/m^3 treated water for lime-polyelectrolyte coagulation) and in the reduced cost of final pH adjustment. The comparative economics, however, are largely dependent upon the cost associated with overcoming the poor dewatering properties associated with the alum sludge. Additional cost of sludge conditioning agents and/or a potential decreased filter yield may possibly negate these potential areas of savings.

8. It is recommended that a series of bench scale tests be conducted to examine additional polyelectrolytes and suitable sludge conditioners that could be utilized to improve the dewatering characteristics of the alum sludge. Other dewatering techniques such as the centrifuge or various gravity-type filters might also be investigated during this phase of the investigation. If these tests prove successful, it is further recommended that the investigation be extended to a pilot scale study. The function of the pilot scale phase would then be to provide indicative chemical cost and operational data for a continuous flow system.

SECTION VI

NEUTRALIZATION OF CAUSTIC WASTEWATERS UTILIZING COAL-FIRED BOILER FLUE GASES

A common problem presently facing many industries utilizing fossil-fired boilers is that of meeting various compliance regulations related to the control of noxious gases and particulate emissions. Removal of these fractions of the flue gas through wet scrubbing techniques often reduces the air pollution problem only to create a water pollution problem. The intent of this phase of the research project was to investigate an integrated solution to this problem whereby the acidic fractions of the flue gas might be utilized to offset the causticity of the dyeing process wastewaters. Neutralization would, as a result, create a wastewater more readily amenable to biological degradation.

The pH of a wastewater is a key factor in the growth of microorganisms which are vital to the biological wastewater treatment process. Generally, the optimum pH level for biological growth lies between 6.5 and 7.5[33]. Most organisms cannot tolerate pH levels above 9.5 or below 4.0. There are, however, some instances where wastewaters having pH levels as high as 12.0 have been successfully treated biologically due to the ability of the microorganisms to produce weak neutralizing acids. At Canton Textile Mills, Inc., the influent to the biological treatment system generally ranges from 10.0 to 12.0 pH units during dyehouse production hours. The wastestreams from the hospital, a residential section, and the domestic wastes from the mill provide much of the biological life needed to properly seed the dyeing process wastewaters for subsequent treatment. Although the hospital and domestic wastestreams are normally within the optimum pH ranges for the biological growth, the dyehouse discharge has pH levels in excess of 10. Thus, when the three streams are combined, the microorganisms receive a pH shock which either kills them or greatly retards their ability to function normally. By adjusting the pH level of the dyehouse wastewater into the proper range thereby reducing the pH shock, it was anticipated that the entire system's efficiency could be improved.

RESEARCH OBJECTIVES

The primary objective of the research performed in conjunction with this phase of the project was to demonstrate the practicability of utilizing coal-fired boiler flue gases to neutralize the causticity of Canton Textile Mills, Inc.'s dyeing process wastewaters. The secondary objectives included the following:

1. Evaluate the effect of flue gas scrubbing on the physical and chemical properties of the wastewaters.

2. Determine the effect of scrubber neutralization on the subsequent biological treatment system.

3. Appraise the efficiency of a conventional wet scrubber utilizing dyehouse caustic wastewaters as the scrubbing media.

4. Investigate the feasibility of utilizing the scrubber installation to permit the burning of low grade, high sulfur coal.

During the early stages of the project, the fourth objective concerning the use of low grade, high sulfur coal was dropped due to the location of the coal fields supplying high sulfur coal, the time factor involved in rail transport, the volume required to be purchased, and the cost factor involved in obtaining this coal.

NEUTRALIZATION PRINCIPLES

The neutralization technique investigated is based primarily upon the same principles employed by the conventional "dual alkali" or "double alkali" processes of desulfurization. These processes utilize soluble sodium based alkali in the forms of sodium hydroxide (NaOH), sodum sulfite (Na_2SO_3), sodium carbonate (Na_2CO_3), or sodium bicarbonate ($NaHCO_3$) to accomplish sulfur dioxide absorption[34]. The main overall absorption reactions are described by the following equations:

$$2NaOH + SO_2 \longrightarrow Na_2SO_3 + H_2O \qquad (06)$$

$$Na_2SO_3 + SO_2 + H_2O \rightleftharpoons 2NaHSO_3 \qquad (07)$$

$$Na_2CO_3 + 2SO_2 + H_2O \longrightarrow 2NaHSO_3 + CO_2 \qquad (08)$$

$$Na_2HCO_3 + SO_2 \longrightarrow NaHSO_3 + CO_2 \qquad (09)$$

Some carbon dioxide removal is also accomplished according to the following reactions:

$$2\ NaOH + CO_2 \longrightarrow Na_2CO_3 + H_2O \qquad (10)$$

$$Na_2CO_3 + CO_2 + H_2O \longrightarrow 2NaHCO_3 \qquad (11)$$

The absorption of carbon dioxide results in the production of sodium species capable of further reaction with the sulfur dioxide fractions of the flue gas. When these subsequent reactions occur in accordance with equations 08 and 09 previously provided, the carbon dioxide is released. Thus, the extent of carbon dioxide absorption depends upon the efficiency of the desulfurization process.

The desulfurization process results in the production of what is commonly referred to as "inactive sodium" or sodium bisulfite and the oxidation product sodium sulfate. Both of these compounds cannot be further reacted with the sulfur dioxide and must be either regenerated or removed from the system. This is typically accomplished by reacting the scrubbing effluent with either lime or limestone according to the following reactions[34].

Lime

$$Ca(OH)_2 + 2NaHSO_3 \longrightarrow Na_2SO_3 + CaSO_3 \cdot \tfrac{1}{2}H_2O \downarrow + 3/2\ H_2O \qquad (12)$$

$$Ca(OH)_2 + Na_2SO_3 + \tfrac{1}{2}H_2O \longrightarrow 2NaOH + CaSO_2 \cdot \tfrac{1}{2}H_2O \downarrow \qquad (13)$$

$$Ca(OH)_2 + Na_2SO_4 + H_2\ O \longrightarrow CaSO_4 \cdot 2H_2O \downarrow + 2NaOH \qquad (14)$$

Limestone

$$CaCO_3 + 2NaHSO_3 + \tfrac{1}{2}H_2O \quad Na_2SO_3 + CaSO_3 \cdot \tfrac{1}{2}H_2O \downarrow + CO_2 + H_2O \qquad (15)$$

Upon removal of the insoluble species resulting from the regeneration process, the regenerated active sodium is returned to the scrubbing system. A much more detailed examination of double alkali process is provided in the literature[34,35,36].

The wastewaters resulting from Canton Textile Mills, Inc.'s dyeing process are particularly suited for use as a scrubbing solution in that they contain "active sodium" species present in the form of sodium hydroxide and sodium sulfite. Therefore, it would appear that utilizing these wastewaters as a scrubbing solution could accomplish the dual purpose of neutralization and flue gas desulfurization.

EXISTING BOILER SYSTEM

The boiler utilized for the neutralization investigations was the coal-fired standby unit which is normally used during periods of interrupted natural gas service. This boiler is a Combustion Engineering, Inc. C-E Vertical Unit which was constructed in 1959. It is a 27 metric ton per hour (60,000 lb/hr) boiler with a maximum pressure of 14 kilograms per square centimeter (200 psi). The boiler furnace burns 3.18cm by 0.95cm (1-1/4" x 3/8") coal fed by a spreader stoker at an approximate rate of 44 metric tons/day. A typical coal analysis is provided in the Appendix as Table A11. The boiler is equipped with a Whirlex dust collector which captures approximately 34 to 45 kilograms/hour (75-100 lbs/hr) of fly ash. A typical profile of the existing stack gases discharged to the atmosphere is provided in Table 24.

The State of Georgia's Department of Natural Resources has established emission standards applicable to Canton Textile Mills, Inc. for both particulate and sulfur dioxide emissions. These standards indicate that the maximum particulate emissions for an existing source (with a rated heat input of 3.4×10^5 Kg-cal/min or 80×10^6 BTU/hr) shall not equal or exceed 16.7 Kg/hr (36.8 lbs/hr). The standards for new sources with a similar capacity is, however, approximately 6.4 Kg/hr (14 lbs/hr)[37]. With the definite possibility that more stringent secondary standards may be adopted in the future, it was felt that it would be desirable for the scrubber system utilized for neutralization to have the additional capabilities of providing for a 62% reduction of particulate emissions, thereby allowing Canton Textile Mills, Inc. to be in compliance with the new source regulations. The maximum sulfur dioxide emissions applicable for Canton Textile Mills, Inc. required that sulfur dioxide emission shall not equal or exceed 56.70 Kg/hr (125 lbs/hr). With an existing emission of 20.86 Kg/hr, it is evident that as long as the 0.8% sulfur coal

Table 24. TYPICAL PROFILE OF EXISTING STACK GAS

Temperature, °C	274
Volume (at actual stack temperature), m^3/min	1164
Volume (at standard temperature and pressure) m^3/min	610
Molecular Weight of Flue Gas, grams/mole	30.02
Particulates, gm/m^3	0.42
Sulfur Dioxide, gm/m^3	0.57
Carbon Dioxide, gm/m^3	162
Carbon Monoxide, gm/m^3	3
Oxygen, gm/m^3	157
Nitrogen Dioxide, mg/m^3	3.38
Nitrogen Monoxide, mg/m^3	10.16
Fuel Rate (at normal operating conditions), Kg-cal/min x 10^6	0.22

is utilized, there should be no problem in meeting the sulfur dioxide regulations even without any further reduction within the proposed scrubber system.

NEUTRALIZATION PILOT PLANT INVESTIGATIONS

The practicabaility of the neutralization concept was first investigated in a pilot-scale installation. The objectives of this phase of the investigation were as follows:

1. Establish preliminary projections of the liquid-gas ratio required for optimum neutralization of the caustic dyeing wastewaters.
2. Investigate the potential effects of flue gas scrubbing on the characteristics of the wastewater.
3. Obtain preliminary information related to the efficiency of flue gas scrubbing with the dyeing process wastewaters.

Description of Pilot Plant

The pilot plant investigation was performed with a wet scrubber test model available through Zurn Air Systems. This unit as shown in Figure 17, is a medium-energy, impingement type wet scrubber capable of handling 56.6 standard cubic meters per minute (2000 scfm) with a pressure drop range of 5 to 24cm (water column). In this unit, the flue gas is impacted with the scrubbing media as the high velocity gases pass through the slat between the inlet bonnets and collecting tubes. The shearing actions of the gases atomize the liquid into a dense spray with cyclone spinning and mixing continuing as the gas-liquid mixture progress up the collecting tube. Final separation of the liquid and gas is accomplished by impingement upon the flooded surface of a deflector. The gases then continue upward, exiting through the discharge plenum, while the liquid is returned to the hopper through a sealed leg. The final treated liquid is discharged from the bottom of the hopper.

Pressure drop across the unit is automatically maintained by controlling the liquid level in the hopper with a differential pressure switch which activates a solenoid valve on the liquid makeup line.

Neutralization Investigations

In the initial series of pilot scrubber investigations, the gas flow was held relatively constant while varying the liquid wastewater flow through the system. The pilot scrubber system was allowed to operate continuously over a period of three to six hours for each test condition (liquid wastewater flow rate) to assure attainment of operational equilibrium. During the test period, the pH of both influent and effluent were monitored to provide an indication of the degree of neutralization obtained at each liquid to gas ratio. The degree of neutralization (expressed as the pilot scrubber effluent pH) achieved for various liquid to gas ratios is shown graphically in Figure 18. Two separate plots over identical liquid to gas ratios were developed to demonstrate the changing characteristics of the wastewater. Based on an average dyeing process wastewater flow of approximately 568 liters per minute (150 gpm) and a typical gas flow rate of 1165 actual cubic meters per minute (41,130 acfm), a full scale system was projected to have a liquid to gas ratio of approximately 0.49 l/m^3. By interpolation, it was projected that a full scale system under similar operating conditions might be expected to achieve a reduction of the wastewater pH from a typical pH range of 10.5 to 12.0 units to a final pH level of approximately 8.0 units. It was, therefore, concluded that scrubber neutralization was feasible. Because it was felt desirable to have the capacity of achieving a slightly greater degree of neutralization in the full scale system, the decision was made to utilize a slightly different scrubber configuration allowing more efficient gas scrubbing.

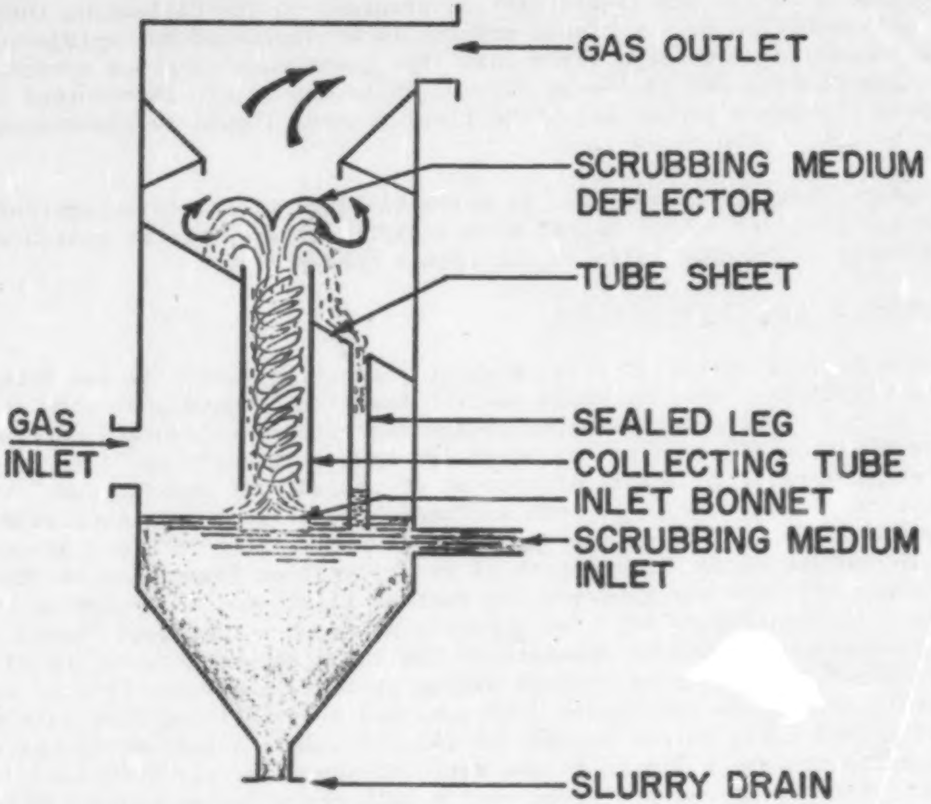
GAS OUTLET
SCRUBBING MEDIUM DEFLECTOR
TUBE SHEET
GAS INLET
SEALED LEG
COLLECTING TUBE
INLET BONNET
SCRUBBING MEDIUM INLET
SLURRY DRAIN

Figure 17. Neutralization pilot plant

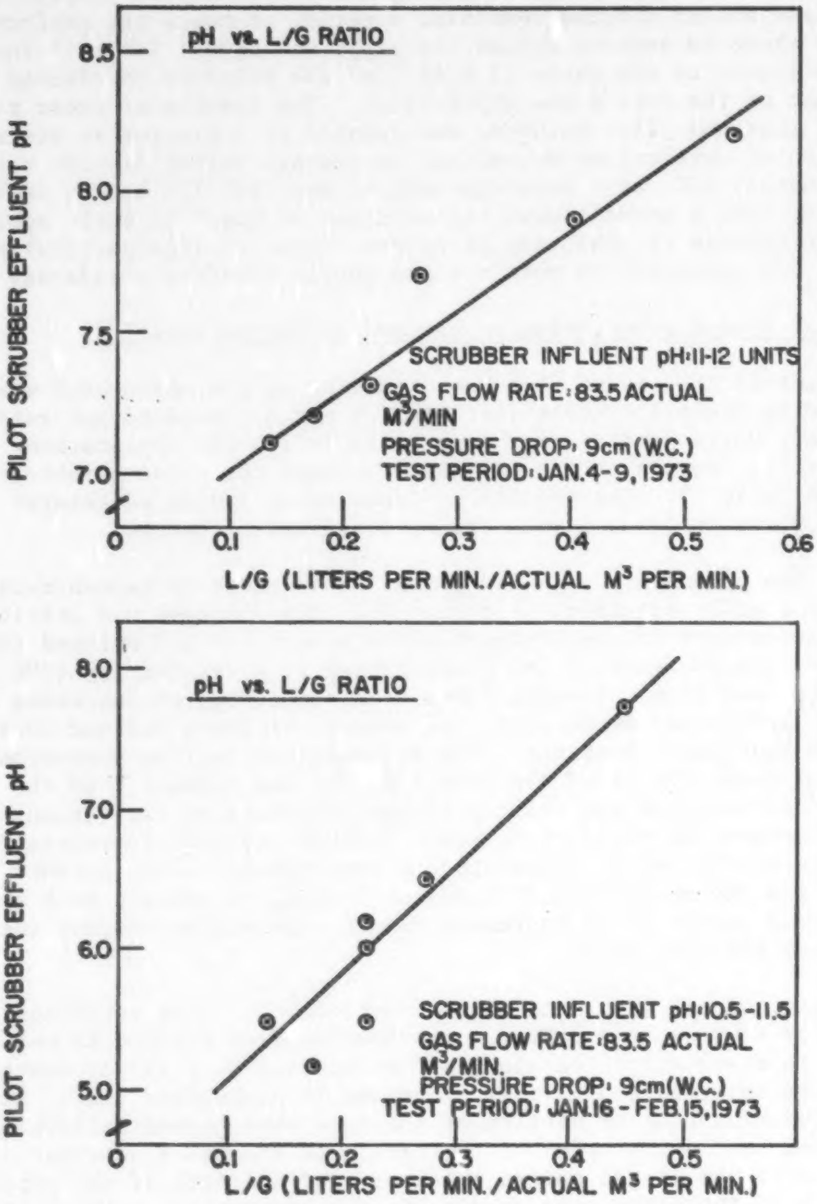

Figure 18. Pilot plant effluent pH vs. liquid/gas ratio.

Pilot Scrubber Efficiency Investigations

To investigate the relative scrubbing efficiencies with respect to particulate and sulfur dioxide removals, a series of tests was performed to monitor these parameters across the pilot scrubber. For this investigation, a liquid to gas ratio of 0.45 l/m^3 was selected to closely approximate that of the full scale application. The results of these tests indicated that the pilot scrubber was capable of achieving an average of 75% reduction of particulate matter and an average sulfur dioxide removal of approximately 40% at a pressure drop of 9cm (w.c.). It was therefore concluded that a conventional wet scrubber on the full scale application would be capable of achieving in excess of the desired particulate reduction of 62% necessary to meet the new source emission standards.

Effect of Flue Gas Scrubbing on Wastewater Characteristics

The potential effects of flue gas scrubbing on the wastewater were also examined in the pilot scale installation for a liquid to gas ratio of 0.45 l/m^3, corresponding to the possible full scale application. A typical characterization of the wastewater across the pilot scrubber is provided in Table 25. The results of these tests indicated several potential problems associated with the neutralization concept.

Most of the parameters examined showed an increase in concentration across the pilot scrubber. A portion of this increase was attributed to vaporization loss in the effluent gas stream. The gas entered the pilot scrubber at approximately 260°C and exited at approximately 60°C at a saturated condition. Several parameters concentration increases were, however, attributed directly to the removal of these various constituents from the flue gas. Both the color and suspended solids concentration increases were felt to be the result of fly ash removal from the flue gas. The sulfate increase was related to the oxidation of the various sulfite species present in the wastestream. The COD and BOD_5 increases respectively were believed to be related to the organic carbon present in the fly ash and the production of oxidizable chemical species such as sulfites which would result in an increased oxygen consumption thereby introducing error into the BOD_5 test.

Two metals, nickel and zinc, showed particularly large increases in concentration across the scrubber. Previous studies related to metals present in desulfurization sludges[38] at several much larger installations have not reported similar increases in nickel and zinc. It is postulated that a major portion of the increased concentrations might be attributed to the corrosion of the metals in the pilot scrubber installation. Corrosion of galvanized steel as used for much of the piping and duct work of the pilot unit results in the liberation of zinc. Also, it is common for a galvanic reaction to occur between dissimilar metals such as galvanized steel of the duct and piping and stainless steel of the pilot scrubber. This reaction could possibly release nickel. In short, it was concluded that nickel and zinc concentration increases of these levels were not attributed to the flue gas scrubbing.

Table 25. WASTEWATER CHARACTERIZATION
ACROSS PILOT SCRUBBER[a]

Parameter	Scrubber Feed	Scrubber Discharge
pH, Units	11.2	7.7
Temperature, °C	30.0	42.5
Total alkalinity, mg/l as Ca_2CO_3	710	210
Total Hardness, mg/l	35	25
Color, APHA Pt. Co. Units	4375	5187
COD, mg/l	922	1046
BOD_5, mg/l	259	302
Suspended Solids, mg/l	212	396
Sulfates, mg/l	78	400
Metals		
Cadmium, µg/l	35	35
Chromium, µg/l	520	660
Copper, µg/l	100	230
Iron, µg/l	550	11700
Lead, µg/l	110	110
Manganese, µg/l	40	245
Nickel, µg/l	330	1260
Zinc, µg/l	296	2570

[a] Data developed at a liquid to gas ratio of 0.45 l/m^3 (actual) corresponding to the possible full scale application.

In evaluating the cummulative effects of flue gas scrubbing on the wastewater, there seemed to be several problems associated with increased concentration levels of certain parameters. It was felt, however, that these increases were insignificant and would not cause problems in the biological treatment system.

FULL SCALE SCRUBBER INSTALLATION

In the selection of the full scale scrubber equipment, consideration was given to operational flexibility and potential scrubbing efficency as well as the relative economics. The medium energy, impingement type scrubber demonstrated the ability to achieve neutralization of the wastewaters to a pH of approximately 8.0 at the liquid to gas ratio equivalent to the full scale application. To allow for flexibility of operation and provide additional neutralization capacity if required, a scrubber configuration more readily lending itself to gas absorption was selected for use in the full scale application. As a result, a venturi type, medium energy (15 to 30cm, w.c.) scrubber manufactured by the FMC/Link-Belt Corporation was purchased. This system as shown schematically in Figure 19, provides a venturi flow constriction with an adjustable wedge to control the pressure drop and particle impaction area. The scrubbing liquid is injected into the gas stream through spray pipes just ahead of the venturi constriction. As the liquid-gas mixture enters the venturi constriction, the gas is accelerated to a high velocity atomizing the scrubbing liquid and causing numerous collisions between the liquid droplets and particulate matter within the gas stream. The flooded elbow connecting the venturi and liquid separator sections provides for additional collision, impaction, and agglomeration of the gas-liquid mixture.

The incorporation of spray pipe liquid injection was of particular importance for this application due to the presence of cotton fibers in the wastewater scrubbing liquid. By utilizing 1.3cm (½ inch) diameter spray pipes rather than small orifices or spray nozzles typical of many other installations, it would be possible to reduce if not eliminate the potential plugging problems. Another important consideration in this scrubber design was the operational flexibility afforded by the adjustable wedge shaped throat insert. By raising and lowering this wedge, it is possible to maintain a constant pressure drop and subsequently a consistent operational performance even with greatly reduced boiler loads as is often experienced on weekends and third shifts.

The full scale scrubber process design as shown in the flow diagram provided as Figure 20 with photographs provided in Figures 21 and 22, allowed for a potential liquid to gas ratio of 0.97 l/m^3 (actual) at the peak gas flows. This high ratio was achieved by providing the capability of scrubbing liquid recirculation. The capability of adjusting both the percentage of recirculation and the liquid to gas ratio was provided to allow additional operational flexibility and to assure achievement of the desired degree of neutralization. Another feature incorporated into the full scale application for flexibility of operation was the

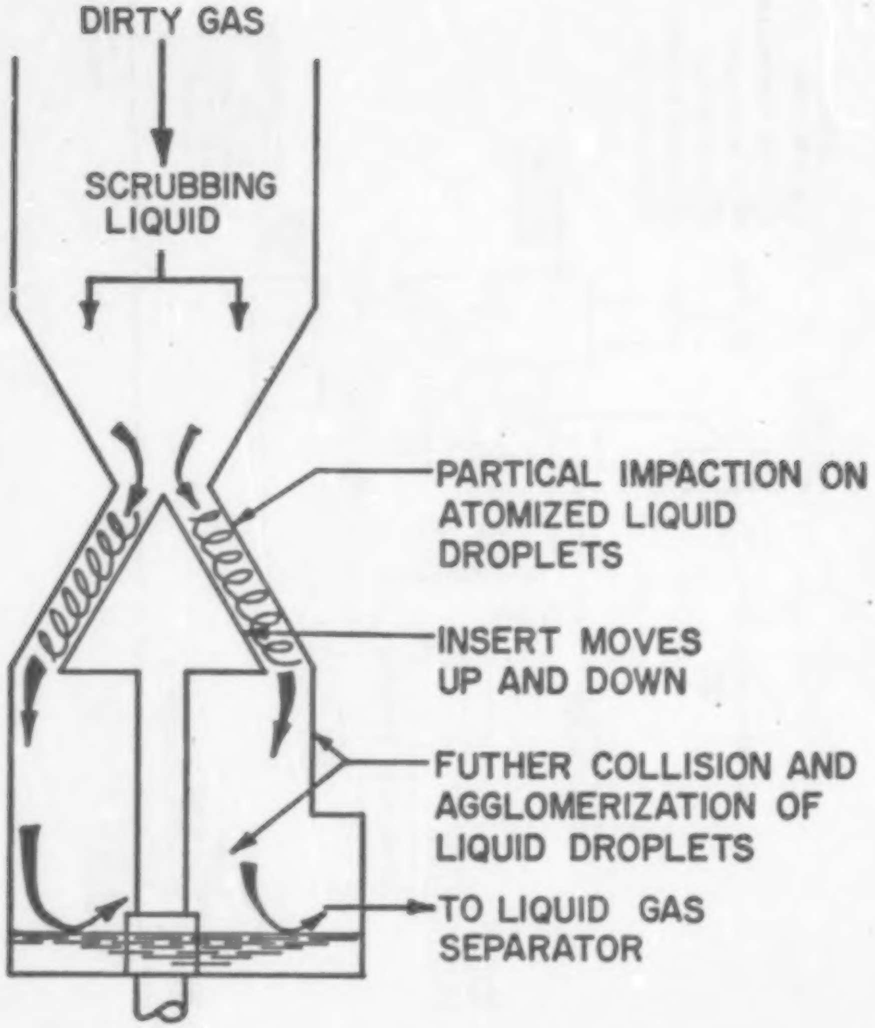
DIRTY GAS
SCRUBBING LIQUID
PARTICAL IMPACTION ON ATOMIZED LIQUID DROPLETS
INSERT MOVES UP AND DOWN
FUTHER COLLISION AND AGGLOMERIZATION OF LIQUID DROPLETS
TO LIQUID GAS SEPARATOR

Figure 19. FMC/Link Belt variable throat scrubber.

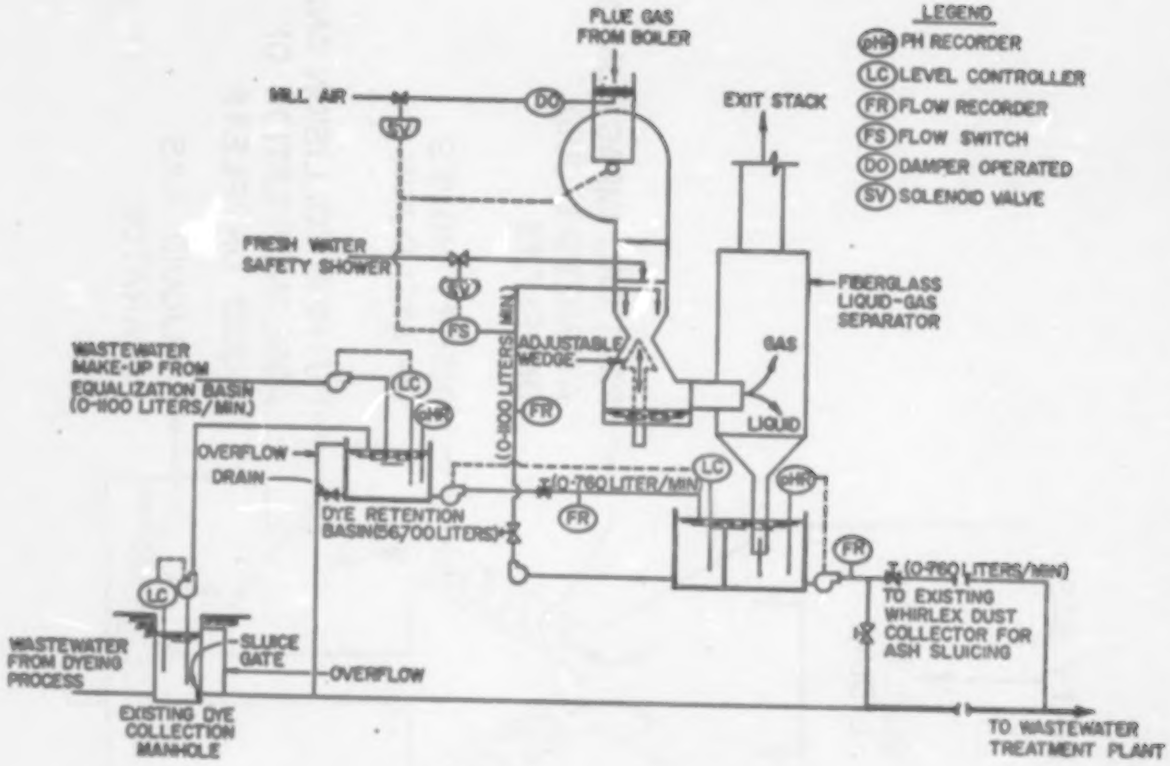
FLUE GAS
FROM BOILER
LEGEND
pHR PH RECORDER
LC LEVEL CONTROLLER
FR FLOW RECORDER
FS FLOW SWITCH
DO DAMPER OPERATED
SV SOLENOID VALVE
MILL AIR
DO
SV
EXIT STACK
FRESH WATER
SAFETY SHOWER
SV
FS
FIBERGLASS
LIQUID-GAS
SEPARATOR
WASTEWATER
MAKE-UP FROM
EQUALIZATION BASIN
(0-1100 LITERS/MIN)
(0-1100 LITERS/MIN)
ADJUSTABLE
WEDGE
GAS
LIQUID
LC
pHR
FR
OVERFLOW
DRAIN
(0-760 LITER/MIN)
LC
pHR
FR
DYE RETENTION
BASIN(56,700 LITERS)
FR
(0-760 LITERS/MIN)
TO EXISTING
WHIRLEX DUST
COLLECTOR FOR
ASH SLUICING
LC
WASTEWATER
FROM DYEING
PROCESS
SLUICE
GATE
OVERFLOW
EXISTING DYE
COLLECTION
MANHOLE
TO WASTEWATER
TREATMENT PLANT

Figure 20. Process flow diagram of scrubber installation

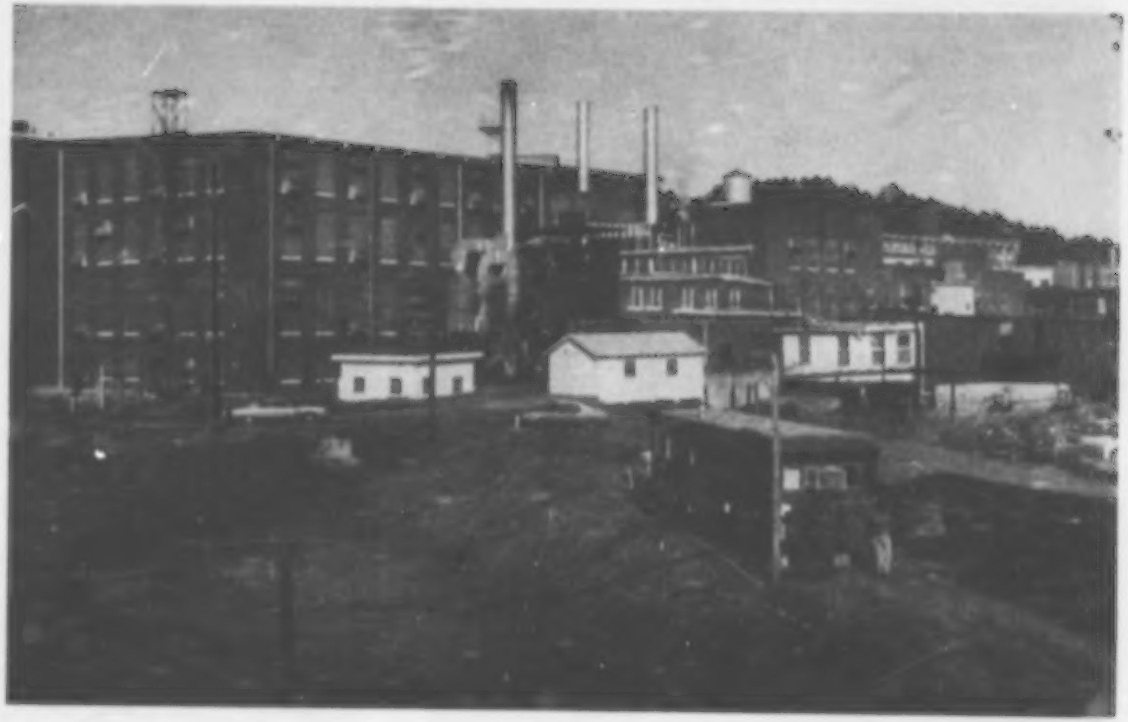

Figure 21. Distant view of Canton Textile Mills, Inc.'s scrubber installation.

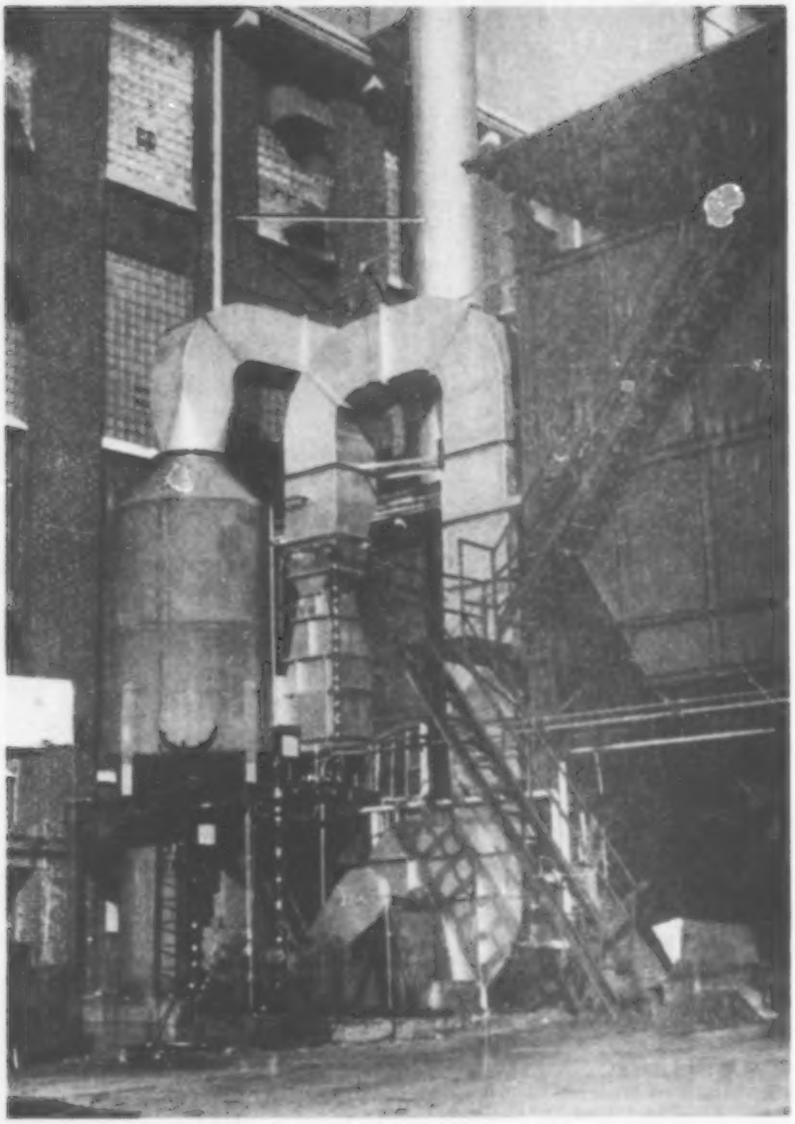

Figure 22. Close-up of Canton Textile Mills, Inc.'s scrubber installation

capability of utilizing the wastewater from the equalization basin as a scrubbing liquid during the periods of low dyehouse production and weekends.

Prior to the addition of the scrubber system, fresh water was utilized for sluicing the fly ash collected in the existing Whirlex dust collector of the coal fired boiler. Fly ash and water were then sent straight to the receiving stream without treatment. In conjunction with the upgrading work performed on the biological treatment system, this wastewater was diverted into the waste treatment system providing for the removal of fly ash within the equalization basin. To conserve both fresh water and reduce the hydraulic loading on the biological system, provisions were made within the scrubber system to utilize the scrubber discharge wastewaters for this purpose.

The potential need for a demister was considered, but concluded as unnecessary. The FMC Corporation indicated that the open design, with no internal sieve plates, baffles, or demisters present was important in avoiding potential plugging and scaling problems. Also, it was felt that sulfuric acid mist would not be a significant problem for this size application.

Upon initial system startup, several operational problems were encountered. Below is a brief outline of the basic problems and steps taken to correct them:

1. A severe plugging problem was encountered in several of the pumps due to the presence of cotton fibers in the wastewater. This problem was temporarily solved by placing a screen basket around the initial scrubber system intake pipe in the dye collection manhole. A more permanent solution to this problem is presently being investigated with the possible use of a hydrasieve or mechanically cleaned screen prior to the scrubber system.

2. The presence of surface-active agents in the dyeing wastewaters produced an unsightly foaming problem in the scrubber sump. Other than the problem created by the overflowing foam, the foam created a false liquid level reading by the capacitance level detector allowing the sump to be pumped dry and in turn activating the safety shower and deactivating the fan. This problem was solved by utilizing a defoamer additive injected into the scrubber feed from the dye retention basin.

3. In the initial design, all pH probes were equipped with ultrasonic cleaners to prevent fouling of the probe. Even with the ultrasonic cleaners, fouling of the various probes has been a continuous trouble area. Another major trouble area experienced with submerged pH probe assemblies is that of obtaining a proper liquid seal. The instrument used for this application utilized an O-ring pressure seal which has failed on numerous occasions permitting liquid seep-

age into the probe assembly. In future installations, consideration should be given to the use of a different type of pH monitoring equipment.

4. The initial scrubber installation utilized an existing carbon steel stack with no mist eliminator. Sulfuric acid mist was not felt to be problem with acid mist emissions ranging from 0.04 to 2.27 kilograms per hour. A slight temperature change of the gas exiting the stack, however, resulted in the condensation of water droplets. These water droplets then reacted with the remaining sulfur dioxide in the gas to form a severely corrosive liquid. To solve this problem, several alternatives are under consideration. One common method utilized to counteract this problem is the use of a flue gas reheater. Reheating of the flue gas is typically accomplished by several methods consisting of direct-fire, flue-gas bypassing, steam injection, or recuperative transfer (transfer of heat from inlet gas to outlet gas through the use of a heat exchanger). Another alternative and the one under consideration at present is the selection of a corrosion resistant stack. The use of a fiberglass stack compatible to the material construction of the scrubber separator is felt to offer the most economical alternative for this application.

FULL SCALE SCRUBBER EVALUATION

The full scale scrubber installation successfully demonstrated the ability to neutralize the wastewater, reduce the particulate and sulfur dioxide emissions, and to do so without any detrimental effect on the biological treatment system.

Neutralization of the wastewaters was readily accomplished with the full scale scrubber system. The scrubber demonstrated the ability of reducing the wastewater pH to levels as low as 4.5 pH units. The additional neutralization capacity of the venture scrubber proved, however, to be in excess of the design expectations resulting in the over neutralization of the wastewaters into the acidic pH ranges. Various scrubber operational conditions were tested in an attempt to produce higher scrubber effluent pH levels. A summary of the various operational variations and effects are presented in Table 26. The results of this testing demonstrated that over the feasible system operating variables, it was not possible to consistently maintain a desired scrubber effluent pH of 7.5-8.0 units. Thus, it was apparent that a reduction must be made in either the volume of gas processed with the scrubber or the volume of the wastewaters neutralized. Because it was desirable to process the entire gas volume to achieve a particulate reduction, the decision was made to reduce the volume of caustic wastewater utilized for scrubbing thereby allowing a portion of the caustic wastewaters to be used to readjust the scrubber effluent pH. It was determined experimentally that by reducing the wastewater volume utilized for scrubbing to 230 liters/min (60 gpm) and by using a minimum scrubbing rate of 380 l/min (100 gpm) or a recirculation factor of approximately 160%, the excess caustic wastewater was

Table 26. TYPICAL RESULTS OF VARIOUS SCRUBBER OPERATING CONDITIONS

System Effluent Flow (1/min)	Scrubbing Liquid Flow Rate (1/min)	Flue Gas Volumetric Flow (act. m^3/min)	L/G ($1/m^3$)	System Influent pH (units)	Scrubbing Liquid pH (units)	System Effluent pH (units)	System Pressure Drop (cm -w.c.)
756	983	519	1.66	11.2	8.9	7.1	17.8
756	983	598	1.64	11.2	8.2	6.6	25.4
756	756	963	0.78	11.1	8.0	6.3	22.6
680	1096	436	2.54	11.0	7.8	6.5	25.4
680	756	452	1.67	10.9	7.4	6.6	24.9
680	567	847	0.67	10.4	10.0	6.6	25.4
529	945	496	1.90	11.0	7.5	6.7	15.2
529	756	673	1.12	11.1	7.5	6.5	25.4
529	680	531	1.28	11.0	7.9	6.8	15.2
227	983	1146	0.86	10.8	6.3	5.3	25.4
227	756	836	0.90	10.4	6.2	4.5	25.4
227	378	925	0.41	10.8	9.6	6.0	25.4

capable of maintaining an influent wastewater treatment system pH of 7.5 to 8.0. With these operating conditions, it was also possible to utilize a small volume of the neutralized, equalization basin wastewaters as make-up for the scrubber system during short periods of dyehouse non-production and without a significant decline in the pH levels of the influent of the biological system. It is, however, doubtful that the scrubber operation with the equalization basin wastewaters could be utilized for periods extending over a day without a significant decline in the pH level of the equalization basin effluent. With the present production schedule of the mill, the scrubber system could be operated continuously during the five day dyehouse production period then turned off during the weekend period of low boiler loading.

Similar to the pilot study, an evaluation of the wastewaters across the scrubber system showed concentration increases for several parameters. Typical profiles of the influent and effluent to the scrubber system at two separate operating conditions are provided in Table 27. In comparing the full scale system with the pilot results, the larger increases in concentration were attributed to the increased recirculation rate, higher scrubber efficiency, as well as the concentration effect resulting from evaporation loss in the exit gas. Again, the increased concentration of both COD and TOC was attributed to the unburned organics within the fly ash. This conclusion is substantiated by a comparison of the soluble values for COD and TOC. While the total COD and TOC increased considerably, the soluble form (with the fly ash removed) remained relatively constant. The increase in BOD concentrations were again concluded to be the result of a high oxygen demand created by the increased sulfite concentration. The fact that the soluble BOD_5 values across the scrubber is relatively constant was attributed to the increased oxidation of the wastewater during the filtration phase of the soluble test. Unlike the results of the pilot scale scrubber, the increases in the metal concentrations were considerably lower. The nickel and zinc concentrations which caused concern in the pilot application were much lower in the full scale application. This supported the previous conclusions regarding the release of nickel and zinc resulting from galvanic corrosion. Iron continued to show a large increase in concentrations across the scrubber; however, these concentrations were not felt to be detrimental to the wastewater treatment.

As expected, the full scale scrubber proved to have a much higher efficiency than the pilot scrubber for both sulfur dioxide and particulate removal. The scrubber demonstrated the ability to successfully remove from 80 to 90% of the incoming particulate. This resulted in exit gas particulate emission ranging from 0.9 to 3.0 Kg/hr. (2 to 6.6 lbs/hr.) which is well below the Georgia Department of Natural Resource's new source standard of approximately 6.4 kg/hr (14 lbs/hr.). Liquid to gas ratios ranging from 2.5 to 15.4 l/m^3 (actual) were evaluated as to their effect on particulate removal; however, there seems to be no correlation readily evident. It is estimated that the total particulate removal including that of the Whirlex dust collector is approximately 94-98%.

Table 27. TYPICAL WASTEWATER CHARACTERIZATIONS ACROSS FULL SCALE SCRUBBER

Scrubber Operating Conditions			
Scrubber Effluent Flow Rate, liters/min		605	227
Scrubbing Liquid Flow Rate, liters/min		850	378
Pressure Drop, cm (w.c.)		23	25

Parameter	Units	Scrubber Influent	Scrubber Effluent	Scrubber Influent	Scrubber Effluent
pH, units		11.2	6.3	10.4	5.7
Phenol. Alkalinity	mg/l as $CaCO_3$	640	0	260	0
Total Alkalinity	mg/l as $CaCO_3$	957	342	584	110
Acidity	mg/l as $CaCO_3$	0	520	0	520
COD	mg/l	1338	1732	1067	4603
COD (soluble)	mg/l	1239	1372	-	-
BOD_5	mg/l	579	824	482	1815
BOD_5 (soluble)	mg/l	629	666	-	-
TOC	mg/l	720	1167	170	610
TOC (soluble)	mg/l	450	437	-	-
Total Solids	mg/l	3681	4128	-	-
Total Volatile Solids	mg/l	614	801	72	872
Suspended Solids	mg/l	117	180	158	2347
Suspended Volatile Solids	mg/l	91	115	72	648
Calcium	µg/l	8.1	4.9	9850	11725
Chromium	µg/l	-	-	BDL[a]	91
Copper	µg/l	-	-	58	355
Iron	µg/l	527	7833	412	28175
Manganese	µg/l	-	-	40	150
Magnesium	µg/l	3.68	4.43	230	370
Nickel	µg/l	-	-	70	205
Zinc	µg/l	351	332	78	378

[a] BDL - Below atomic adsorption spectrophotometer detection limit.

The scrubber was capable of achieving as high as 76% sulfur dioxide removal while reducing the scrubber effluent pH to a level of 4.5 to 5.0. In order to achieve the desired neutralization effect ($pH > 7$), it was, however, necessary to reduce the sulfur dioxide removal efficiency to approximately 29%. The full scale scrubber's capacity for sulfur dioxide removal was found to be a function of the scrubbing liquid's pH level as shown in Figure 23 and also indirectly a function of alkalinity. It has been reported[39] that SO_2 removal is also a function of the liquid to gas ratio. Attempts to derive a correlation between scrubber discharge pH and scrubbing liquid to gas ratios as was found with the pilot system were impractical due to the numerous variables influencing the absorption of sulfur and carbon dioxide. Frequent variations in the alkalinities of the wastewater resulted in a wide scrubber effluent pH range at constant wastewater conditions. Also it was found that the flue gas flow was subject to wide variations of both flow rate and composition. With the excess air of the flue gas ranging to as high as 200% (typical excess air for this type of boiler is normally 30-50%), the concentration of both carbon dioxide and sulfur dioxide were observed to vary quite dramatically. This variation of concentration in turn has a quite pronounced effect on the efficiency of the absorption reaction. Another factor contributing to the system variables is the degree of oxidation of the wastewater prior to scrubbing. The concentration of one of the "active sodium" species (Na_2SO_3) is inversely related to the degree of oxidation of the wastewaters prior to scrubbing.

Effect Of Neutralization On The Biological Treatment System

Assessment of the true effects of neutralization on the performance of the biological treatment system was somewhat hindered by frequent inconsistencies of the wastewater characteristics resulting from dyehouse production trends and the influence of heavy rainwater infiltration. Evaluation of the relative effects of neutralization on a daily basis proved erratic and relatively unsuccessful; however, when averaged over several weeks of monitoring, it was observed that neutralization did aid the biological treatment process. The comparative averages of the monitoring results of the system with and without neutralization as provided in Table 28 led to the following conclusions:

1. Other than in the parameters directly related to flue gas scrubbing (pH, alkalinity, and the various solids parameters), it appears that the effect of flue gas scrubbing on the total influent wastewater is relatively insignificant. In most cases, it is extremely difficult to attribute any change of the average influent wastewater parameters directly to flue gas scrubbing.

2. Neutralization did increase the efficiency of the biological treatment system with respect to BOD_5, COD, and TOC removal. This increased efficiency was directly related to an increased mixed liquor volatile suspended solids concentration (MLVSS). With neutralization, it was possible to maintain a maximum MLVSS concentration within the aeration basin of approximately 2400 mg/l as opposed to

Table 28. COMPARATIVE WASTEWATER TREATMENT CHARACTERIZATION WITH AND WITHOUT SCRUBBER NEUTRALIZATION OF DYEING PROCESS WASTEWATERS

Parameter	Units	Influent to Treatment Plant		Effluent From Equal.Basin		Final Treat. Plant Efflu.	
		W/O Scrubber[a] Neutral.	W/Scrubber[b] Neutral.	W/O Scrubber Neutral.	W/Scrubber Neutral.	W/O Scrubber Neutral.	W/Scrubber Neutral.
pH (units)		9.6	7.1	8.6	7.1	7.4	6.8
P. Alkalinity	(mg/l as $CaCO_3$)	172	0	14	0	0	0
M. Alkalinity	(mg/l as $CaCO_3$)	486	206	351	210	220	82
Acidity	(mg/l as $CaCO_3$)	0	86	0	39	14	18
Hardness	(mg/l as $CaCO_3$)	50	26	50	31	29	25
COD	(mg/l)	585	696	479	439	226	188
BOD	(mg/l)	305	264	281	205	87	42
TOC	(mg/l)	179	191	137	115	84	54
Sulfate	(mg/l)	53	248	184	152	482	389
Total Solids	(mg/l)	1241	992	987	823	985	801
Total Volatile Solids	(mg/l)	195	220	171	170	125	158
Suspended Solids	(mg/l)	115	256	90	100	104	85
Volatile Suspended Solids	(mg/l)	81	150	65	66	68	70
Dissolved Solids	(mg/l)	90	736	897	751	881	678
Iron	(mg/l)	1.35	2.34	1.69	1.64	0.84	1.17
Zinc	(mg/l)	0.082	0.09	0.12	0.11	0.13	0.15
Calcium	(mg/l)	12.0	4.44	13.5	7.34	13.3	5.23
Magnesium	(mg/l)	3.6	2.52	3.2	2.34	3.1	2.38
Flow (liters/min)						945	1085
Average Daily Indigo Dye Range Production During Sample Period	(Kg/day)					20,040	18,820
Average Daily Sulfur Dye Range Production During Sample Period	(Kg/day)					4,320	8,390
Average Daily Total Dyehouse Production During Sample Period	(Kg/day)					24,360	27,210

All analyses were performed on 24 hour composite samples.

[a] Average results of daily monitoring performed during period April 9-15, 1975 on system without neutralization

[b] Average results of daily monitoring performed during the period March 5-18 and April 24- May 1, 1975 on system with scrubber neutralization during 5-day dyehouse production.

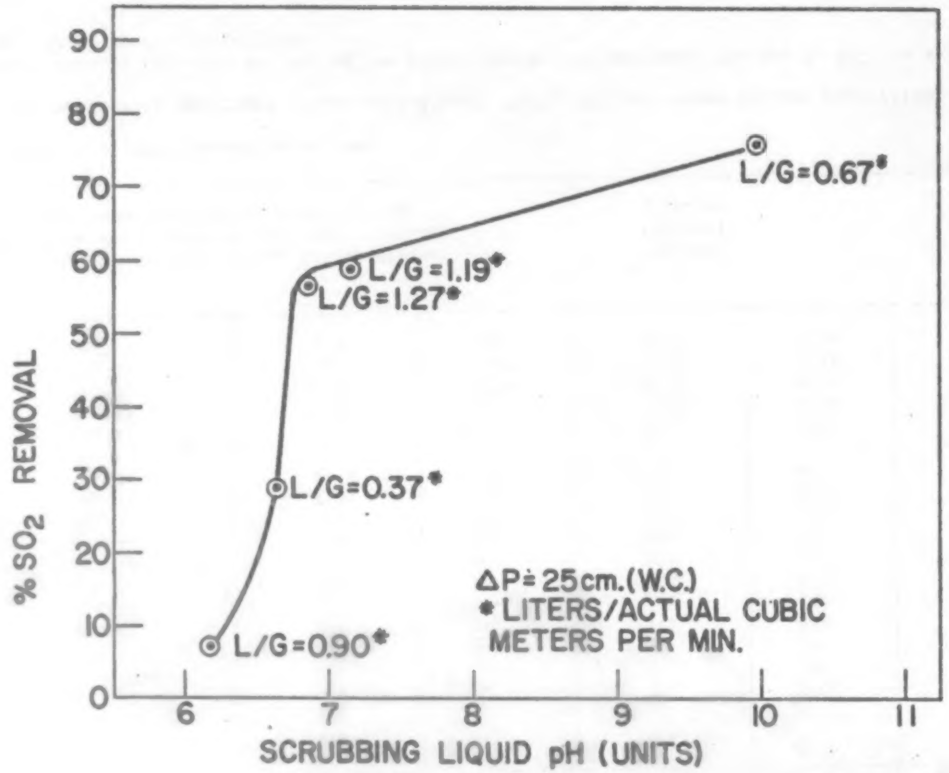

Figure 23. Percent SO_2 removal vs. pH of scrubbing liquid.

1800 mg/l without. It was concluded that the neutralized wastewaters produced a more favorable climate for biomass growth and reproduction.

3. With neutralization, the final effluent wastewaters were less buffered as measured by the alkalinity and acidity. Being less buffered is advantageous because this reduces the chance of influencing the pH level of the receiving stream.

4. The removal of particulates from the flue gas resulted in elevated suspended solids levels in the influent. These suspended solids, however, are removed within the equalization basin and do not influence the biological system. These solids primarily consist of fly ash which will eventually necessitate removal from the equalization basin.

Scrubber Economics

The total cost of the scrubber installation was approximately $138,000 with an estimated operating cost of approximately $30,000 per year. A breakdown of these costs is provided in Table 29. It should be pointed out, however, that many of the material costs are somewhat depressed as a result of cooperation among many of the equipment vendors in supplying equipment for a research-demonstration oriented project.

SUMMARY OF SCRUBBER NEUTRALIZATION CONCLUSIONS AND RECOMMENDATIONS

The results of the scrubber neutralization, demonstration phase of this project lead to the following conclusions:

1. The practicability of utilizing coal-fired boiler flue gases to neutralize caustic wastewaters was proven. Caustic wastewater resulting from Canton Textile Mills, Inc.'s dyeing operation were utilized in conjunction with a conventional wet scrubber to remove a portion of the carbon dioxide and sulfur dioxide fractions of the coal-fired boiler flue gas to successfully reduce the pH level of these wastewaters.

2. Neutralization of the wastewaters by flue gas scrubbing was shown to improve the efficiency of the subsequent biological treatment system by producing a more favorable influent pH and alkalinity while producing relatively insignificant effects upon the other characteristics of the wastewater influent.

3. The scrubber installation demonstrated the ability to achieve in excess of 80% particulate removal from the exit gas stream of a mechanical dust collector reducing the particulate emissions to as low as 0.9 to 3.0 kilograms per hour.

Table 29. CAPITAL AND OPERATING COSTS
OF SCRUBBER SYSTEM

CAPITAL COSTS

Item Description	$ Cost
FMC/Link Belt Scrubber System (with Fiberglass separator and sump)	17,000
I.D. Fan and Motor	8,500
Pumps and Motors	7,500
Instrumentation	15,000
Ductwork	16,200
Electrical	15,300
Foundations and Concrete Work	10,700
Erection	9,600
Piping	20,200
Total Capital Costs	$120,000
Engineering Construction Supervision, Start-up, and other Contingencies	18,000
GRAND TOTAL	$138,000

OPERATING COSTS[a]

Item Description	Yearly $ Cost
Power	18,500
Operating Personnel	5,500
Maintenance	10,000
Total	$ 34,000

---

[a] Does not include the cost of dredging fly ash from equalization basin or landfill disposal.

4. While it was demonstrated possible to achieve up to 76% removal of sulfur dioxide from the flue gas, it was found necessary to optimize the sulfur dioxide removal to achieve the desired neutralization effect. By utilizing a sulfur dioxide removal of approximately 29%, it was possible to produce a neutralized total dyestream having a pH of approximately 7.2 units.

5. The ability of the scrubber system to acidify the entire volume of wastewater might prove especially advantageous should the decision be made to incorporate alum coagulation into the treatment system. Since the optimum pH for alum coagulation occurs at a pH of 5.5 units, the scrubber system might be utilized to produce this pH level and achieve significant savings in chemical costs. Likewise, should the decision be made to proceed with a lime coagulation addition, the scrubber system might be utilized in the final wastewater pH adjustment step. The excess calcium from the lime coagulation process might, however, result in serious scaling problems. In either case, lime or alum coagulation; economics might be significantly improved by incorporation of scrubber neutralization. Further investigation is recommended in this area of application.

SECTION VIII

REFERENCES

1. Georgia Department of Natural Resources (Meeting with Mr. W. M. Jerrigan). Definition of Secondary Treatment. R. S. Noonan, Inc. of South Carolina History No. 008, September 15, 1972.

2. Tenney, M. W. and T. G. Cole. The Use of Fly Ash in Conditioning Biological Sludges for Vacuum Filtration. Journal of Water Pollution Control Federation. 40(8):R281-R302, August 1968.

3. National Lime Association. Ash at Work. 1(2):1-4, 1969.

4. Minnick, L. J. Investigations Relating to the Use of Fly Ash as a Pozzolanic Material and as an Admixture in the Portland Cement Concrete. Proceedings American Society of Testing and Materials. 54:1129-1158, 1958.

5. Tenny, M. W. and W. F. Echelberger, Jr. Fly Ash Utilizing in the Abatement of Polluted Waters. Bureau of Mines Information Circular. 8488:237-265, 1970.

6. Johnson, G. E., L. M. Kunka, A. J. Forney, and J. H. Field. The Use of Coal and Modified Coals as Adsorbents for Removing Organic Contaminants from Wastewater. Bureau of Mines, Report of Inventions. 6884, 1966.

7. Lorenz, K. Secondary Treatment of Power Plant Phenol Waste With Fly Ash and Cinders. Gesundheitsingenieur. 75:189-194, 1954.

8. Weber, W. J., Jr. Physicochemical Processes for Water Quality Control. John Wiley and Sons, Inc., New York. 1972. p 199-259.

9. Boehm, H. P. Chemical Identification of Surface Groups. Advances in Catalysis. Eley, D. D., H. Pine, and P. B. Weisz (Editors), Academic Press, New York. 16:179, 1966.

10. Garten, V. A., D. E. Weiss, ad J. B. Willis. A New Interpretation of the Acid and Base Structure of Carbons. Austrailian Journal of Chemistry. 10:295, 1957.

11. Snoeyink, V. L., and W. J. Beber, Jr. The Surface Chemistry of Active Carbon: A Discussion of Structure and Surface Functional Groups. Environmental Science and Technology. 1:228, 1967.

Preceding page blank

12. Keinath, T. M. and P. D. Holcombe. Process Technology for the Treatment of Textile Finishing Wastewaters - IV, Treatment of Dyeing and Finishing Wastewaters. Department of Environmental Systems Engineering, Clemson University, Clemson, South Carolina. 1972. p 4-9.

13. Porter, J. C., A. R. Abernathy, J. C. Ford, and D. W. Lyons. State of the Art of Textile Wastewater Treatment. Clemson University, Clemson, South Carolina.

14. Lumb, C. Pollution by Textile Effluents in the Mersey Basin. The Cotton, Silk, and Man-Made Fibers Research Association, Shirley Institute, Manchester, England, Pamphlet No. 92. 1966.

15. United States Public Health Service. An Industrial Waste Guide to the Cotton Textile Industry. U. S. Government Printing Office, Washington, D. C. Publication No. 667. 1959.

16. Parsons, W. A. Chemical Treatment of Sewage and Industrial Wastes. National Lime Association, Washington, D. C. 215:1-32, 1965.

17. Mysels, K. J. Introduction to Chemistry. Interscience Publishers, Inc., New York. 1959.

18. Stumn, W. and J. J. Morgan. Chemical Aspects of Coagulation. Journal of American Water Works Association. 54:971, 1962.

19. O'Mella, C. R. A Review of the Coagulation Process. Public Works Journal. 100:87, 1969.

20. Kruyt, H. R. (Editor). Colloidal Science, Volume I. Elsevier Publishing Company, New York. 1952.

21. Stumn, W. and C. R. O'Mella. Stoichiometry of Coagulation. Journal of American Water Works Association. 60:514-539, 1962.

22. EPA Process Design Manual for Suspended Solids Removal, EPA Technology Transfer Program 17030 GNO, Contract No. 14-12-930. October, 1971.

23. Roberts, J. M. and C. P. Roddy. Recovery and Reuse of Alum Sludge. Journal of American Water Works Association. 58(7):857-865, 1960.

24. Thompson, C. G., J. E. Singley, and A. P. Black. Magnesium Carbonate: A Recycled Coagulant - Part I. Journal of American Water Works Association. 64(1):11-19, 1972.

25. Thompson, C. G., J. E. Singley, and A. P. Black. Magnesium Carbonate: A Recycled Coagulant - Part II. Journal of American Water Works Association. 64(2):93-99, 1972.

26. Environmental Science and Technology. Recyclable Coagulants Look Promising for Drinking Water Treatment. Environmental Science and Technology. 74(4):304-305, 1973.

27. South Lake Tahoe Public Utility District. Advanced Wastewater Treatment as Practiced at South Lake Tahoe. EPA Report 17010 ELQ 80/71. 1971.

28. Evans, D. R. and J. C. Wilson. Capital and Operating Cost - AWT. Journal Water Pollution Control Federation. 44(1):1-13, 1972.

29. Kram, D. J. Selection and Use of the Rotary Lime Kiln and Its Auxiliaries. Paper Trade Journal. July, 1972.

30. Beck, A. J., E. N. Sakellariou, and M. Krup. A Method for Evaluating the Variables in Vacuum Filtration of Sludge. Sewage and Industrial Wastes Association. 27(6):689-701, 1965.

31. Vesilind, P. A. Treatment and Disposal of Wastewater Sludges. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan. 1974. p 109-112.

32. Schepman, B. A. and C. F. Cornell. Fundamental Operating Variables in Sewage Sludge Filtration. (A paper presented at 1955 Annual Meeting of Pacific Northwest Sewage and Industrial Wastes Association, Vicoria, B. C. October 27-29, 1955).

33. Metcalf & Eddy, Inc. Wastewater Engineering: Collection, Treatment, Disposal. McGraw Hill, Inc., New York. 1972. p 376-377.

34. Kaplan, N. An Overview of Double Alkali Process for Flue Gas Desulfurization, Atlanta, Georgia. EPA-650/2-74-126-b. November, 1974. p 445-517.

35. Lamantia, C. F., R. R. Lunt, J. E. Oberhaltzer, E. L. Field, and N. Kaplan. EPA-ADL Dual Alkali Program - Interium Results. Proceedings: Symposijm on Flue Gas Desulfurization, Atlant, Georgia. EPA-650/2-74-126-b. November, 1974. p 549-564.

36. Elliott, T. C. SO_2 Removal From Stack Gases. Power. 118(9):51-524, 1974.

37. Georgia Department of Natural Resources. Rules and Regulations for Air Quality Control. Chapter 390-3-1. September, 1973 (Rev.). p 203-242.

38. Rossoff, J., R. C. Rossi, and L. J. Barnstein. Disposal of By-Products from Non-Regenerable Flue Gas Desulfurization Systems. Proceedings: Symposijm on Flue Gas Desulfurization, Atlanta, Georgia. EPA-650/2-74-126-b. November, 1974. p 401-443.

39. Weir, A., J. M. Johnson, D. G. Jones, and S. T. Carlisle. The Horizontal Cross Flow Scurbber. Proceedings: Symposium of Flue Gas Desulfurization, Atlanta, Georgia. EPA-650/2-74-126-b. November, 1974. p 357-400.

APPENDIX

Table A1. DESIGN DATA FOR EXISTING WASTEWATER FACILITIES

A. Mix Box, Bar Screen & Parshall Flume

1. No mechanical or baffle-type mixing provided.
2. Bar Screen is manually cleaned.
3. Parshall Flume (6") with continuous read out flow recorder.

B. Pre-Aeration Tank

1. Modified Imhoff Tank with provisions for diffused air
2. Three sections having total volume of 42,400 gallons (30' x 7' x 9')
3. Air delivery regulated manually with no flow measuring devices on air lines.

C. Lift Station

1. Provides for transfer of wastewater from pre-aeration tank to aeration tank.
2. Three pumps - 175, 275, 400 gpm capacities

D. Biological Aeration Tank

1. Volume - 272,000 gallons (90' x 27' x 15')
2. Air diffusers 3-28' headers with 14 spargers per header for a total of 42 spargers.
3. Two (2) blowers (485 cfm @ 6 psi rated capacities)

E. Secondary Clarifier

1. Volume 39,600 gallons
2. Effluent Weir Length 54.3 feet
3. Sludge return to Aeration Basin (Pump) - 165 gpm capacity
4. No skimmer
5. Overflow Rate - 1820 gpd/ft^2

NOTE: Existing System Designed by R. H. Souther, 1960.

Table A2. DESIGN DATA FOR UPGRADED WASTEWATER TREATMENT FACILITIES

A. Equalization Pond Lift Station
   1. Two pumps - 420 gpm @ 33 feet of water (Head)
   2. Mechanical alternator, float controlled

B. Equalization Pond
   1. Nominal Capacity 1 million gallons
   2. Dimensions - 300' x 60' (top) & 270' x 35' (bottom)

C. Biological Aeration Basin
   1. Reduced air spargers from 42 to 28 to improve mixing effect.
   2. Blowers - changes motor sheaves to achieve maximum rpm rating (680 cfm @ 6 psi & 910 cfm @ 6 psi).

D. Lift Station (to No. 2 Clarifier)
   1. Provides for transfer of wastewater exiting existing clarifier to new No. 2 Clarifier.
   2. Two (2) pumps - each 300 gpm @ 30 ft. head (water).
   3. Mechanical alternator, float controlled.

E. No. 2 Clarifier
   1. Volume - 74,800 gallons (40' dia. x 8' S.W.D.)
   2. Skimmer provided
   3. Design Overflow Rate - 350 gpd/ft^2.
   4. Sludge return to Aeration Basin (via gravity) - 0 to 300 gpm manually controlled.
   5. Weir Length - 122 feet.

F. Aerobic Digester
   1. Volume 74,100 gallons (35' dia. x 10' S.W.D.).
   2. Aerator - 20 HP. (30cfm).
   3. Gravity Drain to Sludge Lagoons.

G. Sludge Lagoons (2)
   1. Volume - 1 @ 142,620 gallons and 1 @ 131,215 gallons.

H. Chlorine Contact Basin
   1. Volume - 2872 gallons (Based on 15 minute retention time @ 190 gpm)
   2. Chlorine solution feed (Cl_2 gas + H_2O) - 100 lbs. Cl_2/day capacity.
   3. 90^o V-notch weir with flow recorder and totalizer.

Table A3. PACKED COLUMN REACTOR TEST WITH UNFILTERED EFFLUENT

A. Test Conditions:
Fly Ash Bed Depth: 16.5 cm
Fly Ash Weight: 200 gm
Mode of Contact: Gravity, Downflow

Elapsed Time (Min.)	Flow Rate ($l/min/m^2$)	Color (APHA Pt.Co. Units)	Total Solids (mg/l)	Susp. Solids (mg/l)
Prefiltered Effl.	-	4375	1845	123
0	55.00	85	3739	137
10	48.08	165	1713	1
20	43.19	1350	1659	2
30	39.93	2000	1732	2

B. Test Conditions:
Fly Ash Bed Depth: 25.4 cm
Fly Ash Weight: 318 gm
Mode of Contact: Gravity, Downflow

Elapsed Time (Min.)	Flow Rate ($l/min/m^2$)	Color (APHA Pt.Co. Units)	Total Solids (mg/l)	Susp. Solids (mg/l)
Raw Effluent	-	3400	1939	78
3	28.11.	30	4072	6
33	15.28	15	1769	7
63	13.73	20	1771	5
123	13.73	1400	1763	19
153	13.73	1600	1733 16	16

Total Volume of Effluent with color (100 APHA Pt. Co. Units = 3.59 liters

C. Test Conditions:
Fly Ash Bed Depth: 42 cm
Fly Ash Weight: 504 gm
Mode of Contact: Gravity, Downflow

Elapsed Time (Min.)	Flow Rate ($l/min/m^2$)	Color (APHA Pt.Co. Units)	Total Solids (mg/l)	Susp. Solids (mg/l)
Raw Effluent	-	1550	1654	50
3	15.12	10	3647	26
33	14.30	10	1523	24
63	12.63	25	1464	16
93	11.53	30	1468	13
124	11.82	50	1477	15
159	12.10	40	1540	16
183	11.82	75	1483	21
213	10.43	200	1506	21
243	7.99	370	1518	20

Total Volume of Effluent with color (100 APHA Pt. Co. Units = 7.60 liters)

Table A4. PACKED COLUMN REACTOR TEST WITH PREFILTERED EFFLUENT[a]

A. Test Conditions:
Fly Ash Bed Depth: 16.5 cm
Fly Ash Weight: 200 gm
Mode of Contact: Gravity, Downflow

Elapsed Time (Min.)	Flow Rate (l/min/m^2)	Color (APHA Pt.Co. Units)	Total Solids (mg/l)	Susp. Solids (mg/l)
Raw Effluent	-	4375	1845	123
Prefiltered Effl.	-	3050	1699	120
0	67.63	15	3600	247
10	63.56	860	1665	17
20	50.52	2150	1615	24
30	48.48	2700	1753	30

B. Test Conditions:
Fly Ash Bed Depth: 25.4 cm
Fly Ash Weight: 318 gm
Mode of Contact: Gravity, Downflow

Elapsed Time (Min.)	Flow Rate (l/min/m^2)	Color (APHA Pt.Co. Units)	Total Solids (mg/l)	Susp. Solids (mg/l)
Raw Effluent	-	3400	1939	78
Prefiltered Effl.	-	1895	977	50
0	25.95	30	3974	6
30	17.11	20	1377	11
60	10.67	35	1173	9
90	10.67	50	1197	9
120	10.67	50	1240	6
150	9.78	60	1225	7
180	7.62	110	1406	9
210	6.11	310	1230	17

C. Test Conditions:
Fly Ash Bed Depth: 40 gm
Fly Ash Weight: 481 gm
Mode of Contact: Gravity, Downflow

Elapsed Time (Min.)	Flow Rate (l/min/m^2)	Color (APHA Pt.Co. Units)	Total Solids (mg/l)	Susp. Solids (mg/l)
Raw Effluent	-	8125	1488	46
3	23.88	10	3544	19
15	20.82	20	1665	9
29	15.60	20	1404	19
50	14.10	20	1380	15
76	12.87	20	1385	11
112	-	40	1361	11
142	13.16	100	1366	11
157	13.49	200	1355	7
172	12.55	310	1366	9

Total Volume of Effluent with color (100 APHA Pt. Co. Units = 5.6 liters

---

[a] Effluent was filtered through 710 micron screen

Table A5. TYPICAL JAR TEST PROCEDURE

Test Apparatus: Phipps and Bird (Six Unit) Multiple Stirrer

Procedure

1. 1.0 liter of wastewater was measured into each jar.
2. Approximately 150 ml. of the 1.0 liter total was placed in a separate 250 beaker.
3. Dry chemicals to be added were weighed on an analytical balance.
4. Dry chemicals were slurried with portions from the 150 ml. volume.
5. Rapid mixing of the wastewater was begun.
6. Chemical slurries were added to the jar; slurry beakers were rinsed thoroughly with the wastewater that remained in the 250 ml. beaker. (Total wastewater volume in each jar was 1.0 liter).
7. Wastewater was rapid mixed at 100 rpm for 2 minutes.
8. Wastewater was flocculated at 20-24 rpm for 15 minutes.
9. Flocs were allowed to settle for 30 minutes.
10. After settling, supernatant was siphoned off for analyses.
11. The low dosage of coagulant that yielded good results in terms of the subject parameter (color) was selected and a second jar series was run with the optimum dosage in all beakers. The pH level of the coagulation was then varied by employing various dosages of acid (H_2SO_4) or alkali (NaOH). Similar procedure was again utilized through the mixing, flocculation, settling steps above and the optimum pH range for the desired effect was selected.

Table A6. BUCHNER FUNNEL TEST PROCEDURE

1. Thirty liters of wastewater were coagulated using the predetermined optimum coagulant dosage. After a period of settling, the sludge was carefully withdrawn. This procedure was repeated until a minimum of four liters of sludge was collected.
2. The combined sludge sample was then analyzed for percent solids.
3. The Buchner funnel apparatus was arranged as illustrated in Figure 12 with two No. 4 Whatman Filters placed in the 9-cm funnel.
4. The filter paper was moistened, vacuum applied, and the water drawn through the filter discarded.
5. Exactly 200 milliliters of the sludge was then poured over the prepared funnel and the vacuum applied.
6. Various vacuums were then applied for selected time periods.
7. At the end of the selected filtration time or upon loss of vacuum, the filtrate and filter cake were analyzed.

Table A7. RESULTS OF BUCHNER FUNNEL TESTS WITH SLUDGE GENERATED FROM ALUM COAGULATION

Test No. 1: 2.0 Minute Filtration
Initial Sludge - 200 ml @ 0.40% Solids

		Vacuum	Filtrate			
Vacuum (in. of Hg)	Sludge Cake (% Solids)	Break (min.)	Volume (ml.)	COD (mg/l)	Color (APHA Pt.Co. Units)	pH (Units)
10	Poor Cake	-	102	-	-	-
15	Poor Cake	-	108	-	-	-
20	Poor Cake	-	120	-	-	-

Test No. 2: 4.0 Minute Filtration
Initial Sludge - 200 ml @ 0.40% Solids

		Vacuum	Filtrate			
Vacuum (in. of Hg)	Sludge Cake (% Solids)	Break (min.)	Volume (ml.)	COD (mg/l)	Color (APHA Pt.Co. Units)	pH (Units)
10	Poor Cake	-	152	-	-	-
15	Poor Cake	-	156	-	-	-
20	Poor Cake	-	158	-	-	-

Test No. 3: 6.0 Minute Filtration
Initial Sludge - 200 ml @ 0.29% Solids

		Vacuum	Filtrate			
Vacuum (in. of Hg)	Sludge Cake (% Solids)	Break (min.)	Volume (ml.)	COD (mg/l)	Color (APHA Pt.Co. Units)	pH (Units)
10	Poor Cake	-	176	-	-	-
15	Poor Cake	-	184	-	-	-
20	Poor Cake	-	188	-	-	-

Test No. 4: 8.0 Minute Filtration
Initial Sludge - 200 ml @ 0.29% Solids

		Vacuum	Filtrate			
Vacuum (in. of Hg)	Sludge Cake (% Solids)	Break (min.)	Volume (ml.)	COD (mg/l)	Color (APHA Pt.Co. Units)	pH (Units)
10	55.7	7.25	188	24	60	4.4
15	60.0	6.75	190	28	70	4.3
20	67.5	6.50	195	20	80	4.5

Table A8. RESULTS OF BUCHNER FUNNEL TESTS WITH SLUDGE GENERATED WITH LIME COAGULATION

Test No. 1: 2.0 Minute Filtration
Initial Sludge - 200 ml @ 2.97% Solids

Vacuum (in. of Hg)	Sludge Cake (% Solids)	Vacuum Break (min.)	Filtrate			
			Volume (ml.)	COD (mg/l)	Color (APHA Pt.Co. Units)	pH (Units)
10	Poor Cake	-	78	-	-	-
15	Poor Cake	-	80	-	-	-
20	Poor Cake	-	82	-	-	-

Test No. 2: 4.0 Minute Filtration
Initial Sludge - 200 ml @ 2.97% Solids

Vacuum (in. of Hg)	Sludge Cake (% Solids)	Vacuum Break (min.)	Filtrate			
			Volume (ml.)	COD (mg/l)	Color (APHA Pt.Co. Units)	pH (Units)
10	Poor Cake	-	144	31	15	11.3
15	Poor Cake	-	148	35	15	11.4
20	Poor Cake	-	154	46	15	11.5

Test No. 3: 6.0 Minute Filtration
Initial Sludge - 200 ml @ 3.75% Solids

Vacuum (in. of Hg)	Sludge Cake (% Solids)	Vacuum Break (min.)	Filtrate			
			Volume (ml.)	COD (mg/l)	Color (APHA Pt.Co. Units)	pH (Units)
10	17.2	-	157	31	15	11.3
15	20.0	-	162	35	15	11.4
20	20.4	-	166	46	15	11.5

Test No. 4: 8.0 Minute Filtration
Initial Sludge - 200 ml @ 2.73% Solids

Vacuum (in. of Hg)	Sludge Cake (% Solids)	Vacuum Break (min.)	Filtrate			
			Volume (ml.)	COD (mg/l)	Color (APHA Pt.Co. Units)	pH (Units)
10	19.6	7.75	181	73	0	11.5
15	43.1	7.50	182	61	20	11.5
20	38.8	7.25	187	58	5	11.5

Table A9. RESULTS OF BUCHNER FUNNEL TESTS WITH SLUDGE GENERATED WITH MAGNESIUM CARBONATE AND LIME COAGULATION

Test No. 1: 2.0 Minute Filtration
Initial Sludge - 200 ml @ 3.01% Solids

			Filtrate			
Vacuum (in. of Hg)	Sludge Cake (% Solids)	Vacuum Break (min.)	Volume (ml.)	COD (mg/l)	Color (APHA Pt.Co. Units)	pH (Units)
10	Poor Cake	-	80	-	-	-
15	Poor Cake	-	82	-	-	-
20	Poor Cake	-	86	-	-	-

Test No. 2: 4.0 Minute Filtration
Initial Sludge - 200 ml @ 3.01% Solids

			Filtrate			
Vacuum (in. of Hg)	Sludge Cake (% Solids)	Vacuum Break (min.)	Volume (ml.)	COD (mg/l)	Color (APHA Pt.Co. Units)	pH (Units)
10	Poor Cake	-	114	-	-	-
15	Poor Cake	-	118	-	-	-
20	Poor Cake	-	122	-	-	-

Test No. 3: 6.0 Minute Filtration
Initial Sludge - 200 ml @ 2.03% Solids

			Filtrate			
Vacuum (in. of Hg)	Sludge Cake (% Solids)	Vacuum Break (min.)	Volume (ml.)	COD (mg/l)	Color (APHA Pt.Co. Units)	pH (Units)
10	Poor Cake	-	180	-	-	-
15	16.4	-	182	46	10	11.5
20	19.8	-	184	50	30	11.5

Test No. 4: 8.0 Minute Filtration
Initial Sludge - 200 ml @ 3.57% Solids

			Filtrate			
Vacuum (in. of Hg)	Sludge Cake (% Solids)	Vacuum Break (min.)	Volume (ml.)	COD (mg/l)	Color (APHA Pt.Co. Units)	pH (Units)
10	26.4	7.25	178	39	10	11.5
15	28.8	6.75	180	31	10	11.5
20	29.9	6.00	182	23	10	11.5

Table A10. RESULTS OF BUCHNER FUNNEL TESTS WITH SLUDGE GENERATED FROM LIME-DOW A-23 COAGULATION

Test No. 1: 2.0 Minute Filtration
Initial Sludge - 200 ml @ 3.84% Solids

			Filtrate			
Vacuum (in. of Hg)	Sludge Cake (% Solids)	Vacuum Break (min.)	Volume (ml.)	COD (mg/l)	Color (APHA Pt.Co. Units)	pH (Units)
10	11.1	-	126	71	20	11.2
15	14.9	-	130	60	15	11.2
20	15.7	-	144	40	15	11.2

Test No. 2: 4.0 Minute Filtration
Initial Sludge - 200 ml @ 4.33% Solids

			Filtrate			
Vacuum (in. of Hg)	Sludge Cake (% Solids)	Vacuum Break (min.)	Volume (ml.)	COD (mg/l)	Color (APHA) Pt.Co. Units)	pH (Units)
10	24.8	-	164	44	30	11.3
15	29.3	3.83	180	36	20	11.4
20	28.1	3.75	180	32	20	11.4

Test No. 3: 6.0 Minute Filtration
Initial Sludge - 200 ml @ 6.48% Solids

			Filtrate			
Vacuum (in. of Hg)	Sludge Cake (% Solids)	Vacuum Break (min.)	Volume (ml.)	COD (mg/l)	Color (APHA Pt.Co. Units)	pH (Units)
10	24.8	4.00	148	63	30	11.4
15	29.3	3.75	160	31	20	11.5
20	28.1	3.50	170	67	20	11.4

Test No. 4: 8.0 Minute Filtration
Initial Sludge - 200 ml @ 5.83% Solids

			Filtrate			
Vacuum (in. of Hg)	Sludge Cake (% Solids)	Vacuum Break (min.)	Volume (ml.)	COD (mg/l)	Color (APHA Pt.Co. Units)	pH (Units)
10	28.2	5.30	156	56	15	11.4
15	28.0	4.75	158	62	20	11.4
20	28.4	4.25	164	59	20	11.4

Table A11. TYPICAL COAL ANALYSIS

Size	3.2cm x 1.0cm (1-1/4 x 3/8 inch)
Moisture (%)	2.76
Ash (%)	5.98
Volatile (%)	40.39
Fixed Carbon (%)	50.87
Sulfur (%)	0.80
Fusion Temperature of Ash (AST)	1454°C (2650°F)
Grindability (Hardgrove)	60
Free Swelling Index (A.S.T.M.) Coke Button	6
Heat Valve (as received)	7562 Kg.-Cal/Kg. (13,600 BTU/lb)
Heat Valve (dry)	7840 Kg.-Cal/Kg. (14,100 BTU/lb)